NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

INTERNETWORKING: EXTENDING LOCAL-AREA NETWORK (LAN) CONNECTIVITY USING ISDN

by

Lauren R. Mihlon

September, 1996

Thesis Advisor:	Don Brutzman
Associate Advisor:	Rex Buddenberg

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1996.

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
INTERNETWORKING: EXTENDING LOCAL-AREA NETWORK (LAN) CONNECTIVITY USING ISDN

5. FUNDING NUMBERS

6. AUTHOR Lauren R. Mihlon

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT

Internetworking is the ability to seamlessly interconnect multiple dissimilar networks globally using the Internet (Brutzman, 96). In order to achieve this network, data links need to provide data speeds which allow applications to function properly. Many important networked applications require high bandwidth to perform effectively. This thesis presents an analysis of Basic Rate Interface (BRI) Integrated Services Digital Network (ISDN) as a data link technology for extending Local-Area Network (LAN) connectivity. Hardware and software capabilities are presented in detail. A representative "ISDN user needs analysis" is also provided. A study is made of an ISDN installation and implementation to determine if ISDN is a viable solution to extending LAN connectivity. Considerations of particular importance include Internet Protocol (IP) compatibility, bonding separate channels to act as a single 128 Kbps logical channel, and native support for IP multicast addressing. Experimental results indicat that ISDN meet most essential requirements.

14. SUBJECT TERMS ISDN, internetworking, LAN connectivity, IP over ISDN, multicasting.

15. NUMBER OF PAGES 141

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTERNETWORKING: EXTENDING LOCAL-AREA NETWORK (LAN) CONNECTIVITY USING ISDN

Lauren R. Mihlon
Major, United States Marine Corps
B.S., United States Naval Academy, 1985

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN INFROMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September 1996

ABSTRACT

Internetworking is the ability to seamlessly interconnect multiple dissimilar networks globally using the Internet (Brutzman, 96). In order to achieve this network, technology needs to provide speeds which will allow the network to function properly. Many applications which are used on this network demand a high bandwidth to perform effectively.

This thesis presents an analysis of Basic Rate Interface (BRI) Integrated Services Digital Network (ISDN) as a data link technology for extending Local-Area Network (LAN) connectivity. Hardware and software capabilities are presented in detail. A representative "ISDN user needs analysis" is also provided. A study is made of an ISDN installation and implementation to determine if ISDN is a viable solution to extending LAN connectivity.

Considerations of particular importance include Internet Protocol(IP) compatibility, bonding separate channels to act as a single 128 Kbps logical channel, and native support for IP multicast addressing. Experimental results indicate that ISDN meets most essential requirements.

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A. PURPOSE OF THESIS

Internetworking is the ability to seamlessly interconnect multiple dissimilar networks globally using the Internet (Brutzman, 96). In order to achieve this network, data links need to provide speeds which allow applications to function properly. Many important networked applications require high bandwidth to perform effectively.

This thesis presents an analysis of Basic Rate Interface (BRI) Integrated Services Digital Network (ISDN) as a data link technology for extending Local-Area Network (LAN) connectivity. Hardware and Software capabilities are presented in detail. A representative ISDN user needs analysis is also provided. We then evaluate the practical employment of ISDN in the Systems Technology Lab (STL) in Root Hall to determine if ISDN is a viable solution.

Considerations of particular importance include Internet Protocol (IP) compatibility, bonding separate channels to act as a single 128 Kbps logical channel, and native support for IP multicast addressing. Experiment results indicate that ISDN meets most essential requirements.

B. MOTIVATION

Many articles have been written on ISDN stating that the acronym stands for “It Still Does Nothing.” ISDN has been in existence for nearly ten years but its slow adoption has meant that ISDN still remains a mystery to many. For most of those ten years, it has been a proprietary implementation by the different telephone companies. There were no standards in place. This meant that different companies made products that supported different features of ISDN and were not interoperable with other ISDN products.

Over the past few years, technology literature has claimed that ISDN has improved. The telephone companies are beginning to understand the technology that they are providing and are capable of trouble shooting problems. Standards are being made to make ISDN and ISDN products interoperable. (Ginsberg, 95)

Many research analysts believe however that the improvements have come too late. They predict that up-and-coming technologies such as cable modems and Asymmetric Data Service Line (ADSL) will make ISDN obsolete (Leeds, 96). Both technologies offer speeds many times that of ISDN and wonder why anyone would bother with ISDN.

This thesis will determine whether ISDN is of immediate practical use. ISDN needs to be evaluated fairly to determine the benefits of this technology, the costs associated with it, and its future growth with the DoD.

1. The Importance Of New Technology In The DoD

Periodically, DoD needs to re-evaluate its mission and determine the requirements need to accomplish its mission. The DoD also needs to have visionaries to determine how the mission will change and what future requirements will be needed. When performing this evaluation, existing technologies need to be examined to determine which technology can support the requirements. The existing technology selected needs to be able to migrate into future technologies.

DoD can't sit back and take a wait-and-see attitude when it comes to technology. There will always be something newer and better just waiting to be developed. DoD needs to be smarter in determining its mission and its requirements to accomplish its mission.

The Internet is essential for many DoD tasks. The DoD need LANs, IP compatibility, telecommuting, IP multicast and bandwidth to be effective in these tasks. ISDN needs to be evaluated to determine it it can provide these requirements for these tasks.

C. THESIS ORGANIZATION

Chapter II identifies related work, in particular how ISDN is presently being used at the Naval Postgraduate School (NPS) and in the private sector. Chapter III is the detailed thesis problem statement. Chapter IV is the evolution of ISDN and how the Regional Bell Operating Companies (RBOCs) market the different ISDN services. Chapter V addresses typical user needs relative to ISDN. Chapter VI examines ISDN-related hardware. Chapter VII is the experimental results and Chapter VIII are the Conclusions and Recommendations.

II. RELATED WORK

A. INTRODUCTION

This chapter discusses work relating to the larger shared objective of how to connect everyone using the Internet. Section B discusses research that was performed using the Multicast Backbone (MBone), a technology that provides global many-to-many real-time audio/video connectivity using the Internet. We believe that MBone compatibility is a key requirement for ISDN use. This section also discusses research occurring at the Naval Postgraduate School (NPS) which examines different technologies that can provide adequate bandwidth to run MBone tools and other applications running across an extended LAN. Section C and D discusses the current usage of ISDN at NPS and in the commercial sector respectively.

B. INFORMATION INFRASTRUCTURE RESEARCH GROUP

The Information Infrastructure Research Group (IIRG) is a team of thesis research students at NPS. Much of the students' research shares a common objective: to connect everyone using the globally shared resource of the Internet. (IIRG, 96)

The following are recently completed NPS theses that relate to connectivity using the MBone. Other related theses document various ways to utilize the MBone tools (as well as other applications) properly.

1. Hamming “Learning to Learn” Multicast Distance Learning

Hamming “Learning to Learn” Multicast Distance Learning (Emswiler, 95) is a thesis that addresses how the MBone and its tools can be used effectively for desktop conferencing and distance learning. “Effective” in this context means the ability to have good audio/video quality across global Internet connections. This thesis addresses the need to provide an interactive and cost effective way to teach and learn. It also shows how MBone is an economically feasible approach for providing widely distributed audio/video for distance learning.

2. Planning and Implementing a Wide-Area Network (WAN)

Internetworking: Planning and Implementing a Wide-Area Network (WAN) for K-12 Schools (Bigelow, 95) is a thesis that documents the planning, design and implementation of a regional WAN connecting K-12 schools, research institutions, libraries and institutions of higher education throughout the Monterey Bay area. The goal of the network is to enable students and educators to have access to the environmental resources available regionally via the Internet, at speeds which will encourage interaction and maintain interest. The thesis documents solutions implemented when connecting this WAN. It also lists deficiencies preventing endorsement of ISDN use as one of the solutions. Those deficiencies are listed in Figure 2.1.

- Basic Rate Interface (BRI) ISDN is unacceptable due to low bandwidth with no compatible upgrade path.
- Current high cost of Primary Rate ISDN is out of reach for schools.
- Vendor hardware solutions are proprietary and not interoperable. Multilink PPP may resolve this, but has not been implemented.

Figure 2.1. Deficiencies preventing endorsement of ISDN use. From (Bigelow, 95).

3. Global ATM Networks for Live Multicast Audio/Video

Internetworking: Using Global ATM Networks for Live Multicast Audio/Video Distribution (Erdogan, 96) is a thesis that documents how distance learning has a positive impact on the quality of education and training for the Monterey Bay area. The thesis shows the implementation of the MBone over Monterey BayNet for educational purposes. The Monterey BayNet is a regional wide-area network (WAN) which connects K-12 schools, libraries, research institutions and institutions of higher education throughout the Monterey Bay Area. This thesis shows that the current MBone technology is possible over a Frame Relay Network. Most of the Frame Relay links tested provide network connections comparable to ISDN at 128 Kbps.

C. ISDN AT NPS

The biggest advertising pitch for ISDN used by the telephone companies has been to handle multiple telephone activities. Like many other organizations' internal telephone office, NPS Base Communications is overloaded with multiple lines. There are not enough analog lines to handle all the employees that need access to a phone, fax or PC. ISDN service allows NPS Base Communications to handle these activities using multiple telephone numbers from a single line. To find out which offices use ISDN for their office needs at NPS, contact Jim Baker at NPS Base Communications.

Except for providing voice telephone service to the school, ISDN lines have only been purchased in limited quantities. There is a Distance Learning Center (DLC) in Root Hall which uses ISDN technology to provide a room-size video teleconferencing (VTC) system. This VTC uses transmission speeds greater than 128 Kbps. Three Basic Rate Interface (BRI) lines, used for data, are “bonded” together to provide the necessary bandwidth. Point of contact for the DLC is Debbie Walsh whose office is Root Hall, Room 256.

Some professors in the Computer Science Department use data ISDN to telecommute from home. Presently, the Computer Science Department has three ISDN lines installed and available to professors who have a need for this technology. Curiously, this high-speed capability is still considered nonessential at NPS. The demand by the user to deliver adequate bandwidth to maintain an acceptable data transfer rate does not outweigh the cost. Point of contact for these three lines is Rosalie Johnson. Her office is located in Spanagel Hall, room 527B.

The Systems Technology Lab (STL) has installed one ISDN line for the purpose of conducting this thesis. They plan to install nine more in the future and have the lines connected to an ISDN hub. If this thesis successfully shows that ISDN supports multicasting, then the STL administrators will use ISDN to telecommute from home to the STL. They want to improve security in the STL by visually checking the lab remotely. Point of contact is Don McGregor whose office is located in Root Hall, room 205D.

D. ISDN IN THE PRIVATE SECTOR

International Data Corporation (IDC) is an independent consultant firm that conducted a survey of telecommunication managers in 1995. The survey was conducted to determine the users opinion and projection for a variety of telecommunication products and services. The services were private-line speeds, data communication services, protocol environments, and the Internet. IDC interviewed telecommunication managers from companies with 100 or more employees from within the seven Regional Bell Operating Company (RBOC) segments. There were about 218 respondents in all. IDC analyzed the respondent's perspective on a regional basis to focus on distinctions among regions. IDC also analyzed the data on an industry basis to focus on distinctions among industries. (Shapiro/Robertson, 95)

1. IDC Findings

Migration from private-line networks is slow. Thirty percent of the managers interviewed predict that their companies will not be migrating from the current private networks at all. However, IDC strongly believes that although the migration path is slow, the increasingly complex maintenance of these networks will drive many corporations to reconsider using alternative services like ISDN and asynchronous transfer mode (ATM) to create a more hybrid approach to their WAN service (Shapiro/Robertson, 95).

Appendix A shows the penetration of some telecommunication services for data traffic: basic exchange, private lines, switched 56 Kbps, and ISDN. Although only 30% of users use BRI ISDN and 16.5% use PRI ISDN, IDC predicts that each of these numbers will increase slowly in the future (Shapiro/Robertson, 95). Appendix A shows the mean and median data regarding number of connections for each service. Furthermore, interest in BRI ISDN has increased. IDC contributes this increase to the interest of remote LAN access and telecommuting. BRI ISDN has had the highest penetration in the agriculture, construction and mining markets.

E. SUMMARY

This chapter addresses related work which demonstrated a relationship between ISDN, the MBone software tools and distance learning. Other related work documents the need to find alternative technology solutions to successfully utilize the MBone tools as well as other bandwidth intensive applications. This chapter also addresses how ISDN is being deployed at NPS now and where some departments plan to use it in the future. Lastly, it shows the slow migration of ISDN in the private sector.

III. PROBLEM STATEMENT

A. INTRODUCTION

The key challenge in network design is providing useful and manageable connectivity for users. More and more organizations are seeing the need to tie together their islands of automation. They are trying to achieve for data services what the telephone system already provides for voice services: the ability to communicate or be connected to another. Connectivity means allowing users to communicate up, down, across, and, in and out of an organization. (Sprague Jr/McNurlin, 93)

This thesis is about just that, providing user connectivity by extending an organization's LAN through the use of ISDN. Section B explains the need for connectivity. Section C explains the problems in achieving connectivity. Section D discusses video teleconferencing (VTC), an application which research has shown aids in communication. It also explains how the MBone technology can be used for VTC. Section E is the problem statement of this thesis; the need to evaluate the potential effectiveness of ISDN for connectivity. Section F discusses why it is important to evaluate ISDN within the Navy and Marine Corps.

B. NEED FOR AN EXTENDED LAN

There are many reasons why organizations are pushing for connectivity outside the organization. Figure 3.1 explains some of the major reasons and is by no means an exhaustive list.

- Economic constraints have caused organizations to look for alternative solutions to in-person meetings, and, education and training requirements that can not be provided locally.
- Geographical dispersion of workers can create problems for collaborative work to be performed.
- Organizations are realizing that employees can be equally or more productive working from their homes. In order to recruit and retain key personnel, organizations are providing their employees with the ability to telecommute from home.
- Transactions between businesses are increasingly being done electronically.

Figure 3.1. Needs for an extended LAN.

C. CONNECTIVITY PROBLEMS AND A SOLUTION: INTERNET PROTOCOL (IP)

The problem with extending connectivity is one of non-interoperabilities. Different machines use different operating systems with different hardware interfaces on different networks. These machines need to be interoperable. It is not always possible (and rarely desirable) to buy end-to-end equipment from the same vendor. The connectivity solution needs to be one that allows the exchange of information in standard ways without physical intervention and without any changes in the command language or in functionality. That is why interoperability must be stressed. Standards are the foundation of the overall architecture because they offer the greatest long-term benefits. Proprietary solutions are to be reserved for filling gaps where standards are not yet available. Therefore, there is only one practical solution for computer connectivity that simultaneously addresses all of these competing requirements: the Internet Protocol (IP).

D. VIDEO CONFERENCE SYSTEM NEEDED IN AN EXTENDED LAN

Video teleconferencing (VTC) is not a new technology. Expensive room-sized systems incorporating specialized hardware and software components have been used for years. Organizations recognize them as productive tools and use them in distance learning and collaborative work. Unfortunately, these systems use proprietary hardware and software and do not interoperate with other computers due to incompatibility with IP.

New video conferencing technology is downsizing these systems to inexpensive software that works on a PC. Desktop conferencing improves the communication process with other users. It allows the users to see each other. The subtleties of body language and facial expressions are communicated in a way not possible via fax machine, e-mail or telephone. As a result, the users avoid wasted time and avert misunderstandings. Additionally, desktop video conferencing systems allow individuals to participate in all functions that room-size systems allowed. As with the room-size VTC, many of these new systems use proprietary hardware and software. There are some however that are not proprietary. (Rettinger, 95)

A great deal of work in recent years has shown that IP-compatible low-cost VTC is possible globally using the MBone.

1. MBone

Internetworking is defined as the ability to seamlessly interconnect multiple dissimilar networks globally (Brutzman, 96). Physical connectivity to the Internet is a prerequisite to internetworking. In the past, most desktop conferencing solutions allowed only two people to participate in a session. This precluded using desktop conferencing for meetings that required the connection of three or more locations. Today, multipoint technology makes it possible for a group of people to see and hear each other and collaborate on a task simultaneously.

The MBone can be considered as a multipoint technology. MBone stands for Multicast Backbone. It is a virtual network layered on top of portions of the physical Internet. The MBone is used for multicast real-time applications such as videoconferencing and audio.

Many related theses demonstrate that the use of the MBone can provide a quality desktop video conference system. The MBone applications provide the necessary tools for distance learning and collaborative work. (Erdogan, 96)

In the past, the MBone technology could only be transmitted over a high-bandwidth physical media (e.g. T1 line at 1.5 Mbps) because it was transmitting audio and video simultaneously. This technology required a large bandwidth due to primitive compression algorithms used to encode audio and video data. Recent developments in MBone software applications and incorporation of sophisticated compression algorithms make it possible for this technology to be used over low-speed network connections.

The MBone technology and associated protocols are becoming standardized by a variety of organizations, most notably the Internet Engineering Taskforce (IETF) Audio-Visual Transport (AVT) working group (Audio/Video Transport Charter, 96). A complete variety of machines and operating systems are already interoperable.

E. ISDN AS A COMPATIBLE SOLUTION

New applications (like the MBone tools) that require a moderately large bandwidth to perform properly are making standard telephone technology inadequate for extending a LAN. The network connectivity demand for higher bandwidth is the driving factor behind searching for a new technology (Wiedenhoeft, 94) (Bigelow, 95). The solution must not only be technically feasible but also cost effective.

The purpose of this thesis is to investigate and evaluate the potential effectiveness of using ISDN for extending a LAN environment. Various forms of ISDN technology has been in existence for over ten years. It remains to be determined whether this technology has matured sufficiently over the years, and whether standards are working that will avoid making ISDN a proprietary solution. A past thesis made a preliminary evaluation of ISDN as a solution for an extended LAN and determined that the ISDN standards and technology were not fully developed (Bigelow, 95).[1]

In 1995, Major Michael R. Macedonia USA, a Ph.D. student at the Naval Postgraduate School (NPS) posted a question to the ISDN news group. He was trying to find out if anyone had successfully used MBone over ISDN. At the time that Major Macedonia posed his question, MBone applications needed more than 128 Kbps to perform properly. Two BRI "bonded" B-channels could not offer the required bandwidth. At that time, a handful of users were using ISDN for IP and MBone

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[1] Bigelow's findings are summarized in Chapter II.

connectivity. However, the usefulness of BRI ISDN for MBone was problematic due to the 128 Kbps constraint.

The ISDN issues that Bigelow's thesis identified and the multicasting problems that Major Macedonia uncovered need to be re-evaluated. This thesis investigates whether show-stopper ISDN problems of the past are still present today.

F. ISDN FOR THE NAVY AND MARINE CORPS

Section B of this chapter addressed many reasons why organizations are pushing for connectivity outside the organization. These reasons can apply to the military as well.

Not only is internetworking important in an office environment, it will become equally important on the battlefield for tactical reasons. We expect that the battlefield commander will need to rely on internetworking in order to achieve cooperative engagement (Nierle, 96). Previous theses have shown the need for applications to conform to IP (Bigelow, 95) (Nierle, 96). IP is essential to assure universal interoperability and hardware-independent evolution of tactical applications. With this in mind, information managers in the military have the responsibility to evaluate new technologies and find the one that bests supports the needs of the organization and supports IP. One such candidate technology is ISDN.

G. SUMMARY

This chapter addresses the need for user connectivity by extending an organization's LAN and the problems to achieve it. It addresses VTC which is a system used in an extended LAN environment. Many VTCs however use proprietary hardware and software which create interoperability issues. The MBone technology and associated protocols have been successfully used in VTC to achieve interoperability. However, the MBone application tools require a moderately large bandwidth (128 Kbps) to perform properly.

Many technologies are emerging which are possible solutions for providing the necessary bandwidth to transmit the MBone application tools. The technology chosen needs to provide interoperability standards to enable extended connectivity and also be cost effective. This chapter addresses the need to investigate the current state of the ISDN technology and evaluate the potential effectiveness of using it for extending a LAN environment within the military.

IV. TELEPHONE COMPANIES ISDN DEPLOYMENT

A. INTRODUCTION

This chapter addresses how the Regional Bell Operating Companies (RBOCs) deployment of ISDN differs from RBOC to RBOC. Section B addresses the evolution of ISDN. Section C addresses the International Standards for ISDN. Section D addresses the different services that each RBOC provides.

B. EVOLUTION OF ISDN

Thirty years ago the entire telephone network was analog. Information was transported through the network as an analog signal from point to point. Computer information, which is digital, had to be converted first to analog before being transported across the network.

During the next two decades, the telecommunications network in the U.S. went through a digital evolution. This digital evolution began with the advent of T-carrier, a digital interoffice transmission system with an analog stored program controlled switch (Bellcore, 85). The T-carrier allowed the phone companies to stop making analog connections between the central offices (COs). When a person's voice or analog modem signal reaches one central office, it is promptly digitized. The digital information is then transferred via switches to the receiving central office. At the receiving central office, the digital information is converted back into an analog signal and continues to its destination point.

During the past decade, the concept of digital connectivity has continued. ISDN is a technology based on this concept. It is a network architecture which through standardization of user and network interfaces allows customer access to multiple communication services (Bellcore, 85). Information is transported through the network in digital form from the customer premises to its destination point. The network is "integrated" in that the system facilities provide end-to-end digital connectivity for voice, data and video services. Computers can connect directly to the telephone network without first converting their signals to an analog audio signal (as modems do).

The concept of digital connectivity has begun to rapidly influence the trend towards more sophisticated applications that require large bandwidths to perform properly. The bandwidths that are required for these applications are more than what is allocated to an analog phone line.

C. INTERNATIONAL STANDARDS FOR ISDN

The international telecommunications standardization organization which is now known as the Telecommunications Standards Bureau (TSB) has played a key role in developing standards. The Bureau was formerly the Consultative Committee for International Telegraph and Telephone (CCITT).

In 1984, two types of user-network interfaces were standardized by the TSB for ISDN: Basic Rate Interface (BRI) and Primary Rate Interface (PRI).

1. Basic Rate Interface (BRI)

The BRI ISDN connection contains three separate channels: two B channels and one D channel. Some documentation refers to these channels as "pipes." The two B (for bearer) channels transmits the user information and are typically 64 Kilobits per second (Kbps) data channels. The D (for data) channel carries call-setup and signaling data (also known as out-of-band signaling) between the ISDN device and the phone company. It is not normally used for anything else. This channel is 16 Kbps. The two B channels can combine together to form a single 128 Kbps data channel through a process called "bonding."[1] The standard BRI is referred to as a 2B+D connection. The BRI ISDN channel is shown in Figure 4.1. (Pacific Bell, 94)

The signaling information tells the telephone company switches what to do with the data that's being delivered via the B channel. This signaling information opens and closes circuit switches to route calls along a dedicated path between caller and receiver. As mentioned previously, standard ISDN uses out-of-band signaling via the data (D) channel. In-band signaling refers to the delivery of the signaling information being carried in the same channel as the user information (in the bearer channel). (Angell, 95)

Some local telephone companies are slow to implement out-of-band signaling connections and use in-band signaling. The in-band signaling uses 8 Kbps in the B channel causing the B channel to only transmit data at 56 Kbps instead of the standard 64 Kbps.

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[1] Protocols for achieving 128 Kbps transmission are addressed further in Chapter V.

Pacific Bell (PacBell) does not offer out-of-band signaling in the Monterey area (although their ISDN sales representatives say they do).

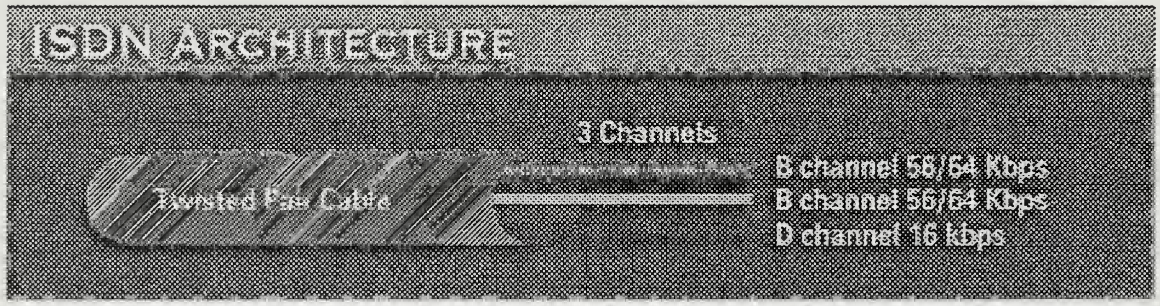

Figure 4.1. Basic Rate Interface (BRI) ISDN channels. From (Pacific Bell, 94).

2. Primary Rate Interface (PRI)

Primary Rate Interface (PRI) consists of 23 64 Kbps B channels and one 64 Kbps D channel. It is referred to as 23B + D. One PRI line is much cheaper than eleven and a half BRI lines. If users need a large number of ISDN lines in one place or need a line that can transmit more than 128 Kbps, PRI should be used. Using one PRI line or multiple BRI lines is more cost effective than using a standard T1 line.

D. REGIONAL BELL OPERATING COMPANIES (RBOC) ISDN DEPLOYMENT

Dedicated digital telephone lines have been around for a long time. They are leased lines that operate 24 hours each day for a fixed monthly rate. There are no connection-by-connection usage charges associated with dedicated lines. ISDN is not considered a dedicated system.

ISDN is an on-demand system and is treated in many ways like plain old telephone service (POTS) in terms of charges. If a person makes a local call, the local telephone company charges the person for that call. If a person makes a long-distance call, the long-distance telephone company charges for the call. ISDN billing works similarly. Therefore it is impractical to use an ISDN line as a dedicated connection 24 hours a day since billing tariffs are not economical.

In 1992, the Regional Bell Operating Companies (RBOCs) and network switching system manufactures made an agreement to provide standard ISDN services. This commitment is called National ISDN. National ISDN specifies the way that telephones and computers communicate with the ISDN network. The National ISDN agreement ensures that each central office switch operates in a standard way, providing a uniform interface to the Customer Premises Equipment (CPE). (U. S. West, 96)

In recent years the United States has had seven RBOCs.[2] Each company provides telephone services for that region. In addition to the RBOCs, there are independent telephone companies (ITCs). All of these companies provide local service. Long distance telephone companies are called InterExchange Carriers (IC or IEC). They provide service between local telephone companies. With the Telecommunications Deregulation Act of 1996, the IECs can now compete in the local market as well (S.652, 96). These companies operate independently which results in uneven ISDN service availability, pricing and service. Sometimes it is difficult to get reliable, consistent answers from these providers about their ISDN services.

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[2] Pacific Bell is merging with South Western Bell and Bell Atlantic is merging with NYNEX. When this happens, there will be five RBOCs instead of seven.

Some telephone companies are trying to make ISDN easy to use. They are constantly updating their office equipment to comply with TSB standards. These companies are using aggressive marketing strategies to sell ISDN as the latest and greatest in modern technology. Other telephone companies continue to be sluggish in ISDN implementation. They are waiting for the market to come to them. However, the demand for ISDN in these areas will never increase if the ISDN equipment manufacturers and local telephone company do not collaborate and market the product. (Angell, 96)

1. Different ISDN Services

Although the BRI standard is 2B+D, different telephone companies offer a variety of BRI channel configurations. The BRI channel configuration determines the type of information that gets transmitted through each B channel. Therefore it is important for the user to know beforehand what the requirements for the ISDN line are before ordering the service. If user needs requirements change, the channel configuration may change (and the phone company will charge for the change). Figure 4.2 lists the available BRI channel configuration options:

Interface Type	Interface Configuration
0B+D	D Channel Only
1B	1B Voice
1B	1B Data
1B	1B Alternate Voice/Data
1B	1B Packet Data
1B+D	1B Voice, D Packet Data
1B+D	1B Data, D Packet Data
1B+D	1B Alternate Voice/Data, D Packet Data
2B	1B Voice, 1B Data
2B	1B Voice, 1B Packet
2B	2B Data
2B	1B Data, 1B Voice/Data
2B	1B Data, 1B Packet Data
2B	1B Voice/Data, 1B Packet Data
2B+D	1B Voice, 1B Packet Data
2B+D	2B Data, D Packet Data
2B+D	1B Data, 1B Voice/Data, D Packet Data

Figure 4.2. BRI channel configuration options. From (Angell, 95).

Most ISDN equipment is flexible enough to operate on any ISDN line. The local telephone company has special ISDN ordering operators so they can assist the user in determining which service is appropriate.

2. Different Telephone Company Switching Systems

A switch refers to electronic facilities that route telephone traffic from one destination to another. ISDN service is a circuit switching system. The term *circuit switching* means that the communications pathway remains fixed for the duration of the call and is unavailable to other users. Electronic switching software operated on specialize switching computers provides the basis for the operation of ISDN.
(Angell, 95)

By way of contrast, the term *packet switching* refers to the sending of data in packets that are individually sent by the most efficient route and then reassembled at their destination. IP packets sent by a single users computers pass through the point-to-point ISDN connection and are then connected to a LAN, where they can be routed anywhere on the Internet.

The leading digital circuit switches used by RBOC are AT&T's 5ESS (Electronic Switching System) and Northern Telecom's (NT) DMS-100 switches. The 5ESS uses either Custom or National ISDN 1 (NI-1) software and the DMS-100 uses only NI-1 software. (Angell, 95)

These switches (and their associated software) have become standard because compatibility between user ISDN equipment and the telephone company's switch is necessary to communicate via ISDN. Therefore, when ordering ISDN service, the user needs to tell the telephone company the exact brand and model of the equipment that will be used on the ISDN line.

3. Inconsistent ISDN Pricing

ISDN pricing policies are called tariffs by the phone companies. The tariff is based on complex cost allocations and recovery rules established by federal and state regulators.[3] Therefore, ISDN pricing varies from one RBOC to another and from state to state. For example, the California Public Utilities Commission (CPUC) recently changed its order and related pricing rules on March 13, 1996 (Pacific Bell, 96). This provided new guidelines for PacBell to resell its products and services.

The CPUC's order moved ISDN into a competitive product category. This means that the product is divided into separate components (e.g. usage, monthly fee and installation). Each cost component is priced separately to enable the company to recover its expenses in accordance with regulatory rules. As a result, the various cost components may no longer subsidize each other. (Pacific Bell, 96)

As a result of this order, PacBell filed its new tariff with the CPUC. It proposed raising the monthly fee by $8. The increase was filed because PacBell originally expected only 12 percent of its ISDN customers to require repeaters. It has found that 24 percent of business ISDN users and 30 percent of personal ISDN users are located more than 3 miles from the central office. PacBell was not charging extra for repeaters. The cost to provision and maintain high-quality, high-speed digital lines in rural areas is higher than in metropolitan areas. PacBell's analyses showed that their current prices would not sustain their ISDN service offerings. (Pacific Bell, 96)

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[3] Tariffs are not based on competition.

The total cost to receive ISDN services is dependent upon the configuration option chosen above, installation costs, distance charges, usage charges and a fixed monthly fee. Continued variation in pricing can be expected to continue as the telecommunications industry is deregulated, services improve and competition increases. Further reduction in costs for educational connectivity is likely in this rapidly changing environment. Appendix B shows the current tariffs and installation costs for each of the RBOCs.

4. Joint Marketing/Alliance Agreements with the Local Exchange Carrier (LEC)

In order to market ISDN better, the telephone companies and ISDN equipment vendors have been working together to make setting up a connection easier. Each Local Exchange Carrier (LEC) has been forming alliances with CPE vendors that allow both parties to jointly sell their products. The joint selling approach focuses on delivery of a complete solution for a customer's application. Under this type of program, ISDN services can be standardized for that RBOC area. With standardization, vendors can ensure interoperability of equipment.

Several RBOCs have facilities for testing ISDN CPE and applications. The testing is divided into three categories: ISDN Protocol Compatibility Testing, Interoperability Testing and ISDN CPE "SUPER" Testing. "SUPER" testing includes human factors testing (Bellcore, 96). The phone companies have a list of approved ISDN vendors and products that work with that LEC's switches.

E. SUMMARY

This chapter addresses the evolution of ISDN and the ISDN International Standards. It also addresses how the Regional Bell Operating Companies (RBOCs) deployment of ISDN differs from RBOC to RBOC.

V. USER NEEDS ANALYSIS RELATIVE TO ISDN

A. INTRODUCTION

This chapter gives an analysis of user needs for an extended LAN relative to ISDN capabilities. Section B deals with the applications used in an extended LAN. In order to have these applications, the user needs a technology that will support these applications. User applications provide the driving requirements.

Sections C through E describe what functions ISDN needs to support. Specifically, section C explains the Transmission Control Protocol/ Internet Protocol (TCP/IP) standards and the Open Systems Interconnection (OSI) reference model. The ISDN reference model is mapped to OSI and TCP/IP to explain how it is technically possible to interconnect two systems using ISDN.

Section D explains the different functions of ISDN that cannot be directly mapped to layers in these well-known reference models. The different ISDN functions are needed to provide a standard to achieve interoperability between two systems and to explain how the technology can provide the necessary bandwidth to run the user's software applications.

Section E describes multicasting which is an inherent requirement for an extended LAN environment. MBone technology is an example of a network that requires multicasting. The MBone application tools are selected to test whether ISDN supports multicasting.

Section F gives an economic analysis of how much it will cost a command to extend their LAN connectivity using ISDN.

B. SOFTWARE APPLICATIONS

The typical office connection with analog lines looks like Figure 5.1: a telephone for voice, a fax device to send documents, and a telephone modem to connect remotely to a LAN or to the Internet. If users have only one Plain Old Telephone Service (POTS) line, they can only make one of these connections at a time. Ordinarily, to conduct multiple tasks at the same time, you must have a separate analog line for each device.

ISDN can allow multiple dissimilar connections simultaneously. The digital connection of ISDN can deliver up to three separate calls at one time (given the appropriate ISDN-capable telephone devices and line configuration). An analog line delivers one call at a time. Figure 5.1 compares an office setup using either one analog line or an ISDN setup.

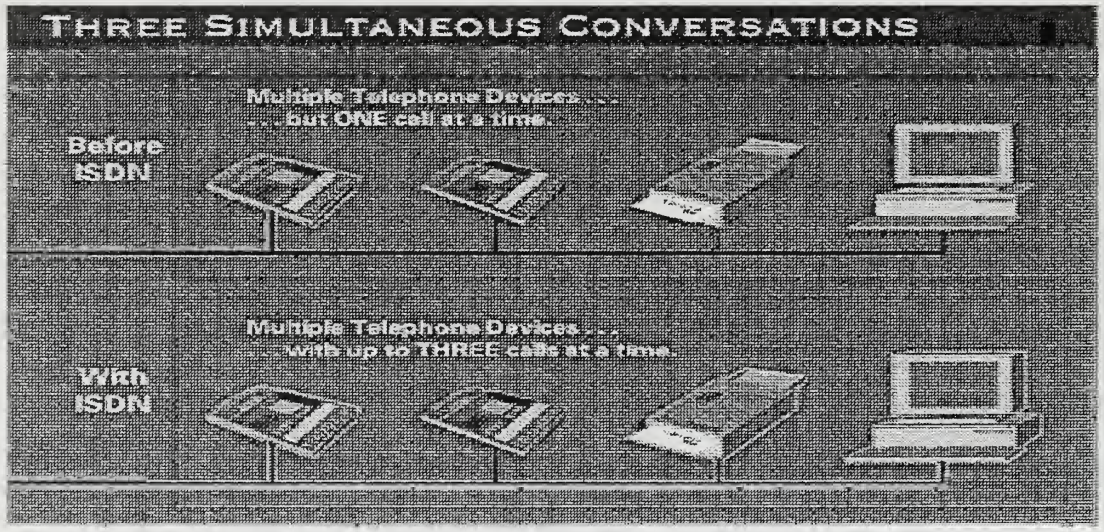

Figure 5.1. Analog vs. ISDN. From (Pacific Bell, 94).

The combined voice and data capabilities of ISDN can support a broad range of applications. However, unlike traditional POTS phone lines which all work alike, ISDN lines must be configured to the user's applications. For example, the setup and equipment for a LAN-extension environment is different from the setup and equipment of a room-sized video teleconference (VTC) application, or an environment where the user is carrying on simultaneous voice and data traffic. This thesis only covers IP-based applications which extends the user's LAN environment.[1]

1. Telecommuting

Telecommuters are employees who work from home part or full time. The idea of telecommuting using ISDN is to transport most of the functionality of the office to the home. Typical office functions pertinent to the use of ISDN are included in Figure 5.2.

- High-speed access to the user's LAN and file servers.
- Fast interconnections to other company LANs or hosts, remote systems.
- Interconnections to other networks especially the Internet.
- Access to and the ability to use electronic mail (e-mail).
- Teleconferenced meetings using Multicast Backbone (MBone) applications.

Figure 5.2. Office functionality needs for telecommuting.

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[1] The ISDN line used for this extended LAN is a 2B+D line for data only. Different line configurations are explained in Chapter IV.

In order to achieve this extended LAN, the user needs a technology that can support more bandwidth than a 28.8 Kbps modem provides. Bandwidth means data transmission capacity. The greater the bandwidth, the more data can pass through the media in a given amount of time. Many new applications require a lot of bandwidth to maintain a data transfer rate acceptable to the user. The demand for this bandwidth by applications is the driving force in finding alternative technological solutions to analog telephone lines. (Wiedenhoeft, 94)

A POTS line can support a 28.8 Kbps modem which can provide certain office functions adequately (e.g. e-mail, file transfer, slow Internet access). However, as graphical user interfaces in Web browsers (e.g. Netscape) become the standard interface on the Internet, users demand higher-speed connectivity to the Internet. It is not practical to use 28.8 Kbps modems to retrieve large graphics, audio or video files over the Internet because the modem speeds are slow. The user will find that it will take a long time to upload applications or download information. Exceptionally long transfers also run the risk of losing the entire transfer if connection reliability is poor. Since personnel costs and productivity are paramount, it is easy to understand why proper network support is crucial.

Desktop VTC is another example of a multimedia application that is needed in an extended LAN environment and requires a lot of bandwidth.[2] VTC depends on the ability to communicate from one-to-many or many-to-many hosts. Current studies show

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[2] VTC is addressed as a need for an extended LAN in Chapter III.

that the MBone can provide an economically feasible desktop VTC system (Erdogan, 96) (Rettinger, 95) (Tiddy, 96). With sophisticated compression control algorithms, the new MBone tools can run effectively over a 128 Kbps bandwidth. MBone also requires standard IP connectivity to support multicasting. This thesis tests if it is technically feasible to use ISDN technology to support a desktop VTC system. Multicasting and MBone application tools are explained further in section E.

C. ISDN REFERENCE MODEL

Both TCP/IP and OSI explain how computers of all sizes, from many different computer vendors running totally different operating systems, can effectively communicate with each other. No matter how different, two systems can communicate effectively if they have the following attributes in common (Figure 5.3):

- Functions: they implement the same set of communications functions.
- Organization: these functions are organized into the same set of layers. Peer layers must provide the same functions, but note that it is not necessary that they provide them in the same way.
- Protocol: peer layers must share a common protocol.

Figure 5.3. Common attributes for communicating systems. From (Stallings, 88).

Each model is based on functional layers to define the communication capabilities needed to enable any two machines to communicate with each other. A *protocol* is a set of conventions to describe the rules of communications between entities in a communications environment. Communication is achieved by having corresponding entities in the same layer in two different systems communicate through protocols.

The OSI is the most widely discussed network reference model but is of little practical interest since it is not widely implemented. The TCP/IP protocol suite, on the other hand, is widely implemented because of the ubiquitous nature of the Internet. Although ISDN does not directly depend on TCP/IP or OSI, the two models can be used to map out and illustrate ISDN's protocol architecture to explain how to connect ISDN devices and higher-layer services. The TCP/IP and OSI models are presented first so that they can be compared with ISDN's protocol architecture.

1. TCP/IP

Networking protocols are normally developed in layers, with each layer responsible for a different facet of the communications. This division of labor is to provide clarity and interoperability among software components. TCP/IP is certainly the most widely implemented set of protocols because of the Internet. It is normally considered to be a 4-layer system as shown in Figure 5.4. This protocol suite defines and routes datagrams across the Internet and provides connectionless transport service. The TCP/IP protocol uses packet switching (i.e. routing). TCP provides reliable delivery, while UDP provides a best effort (i.e. unreliable) service to deliver its packets.

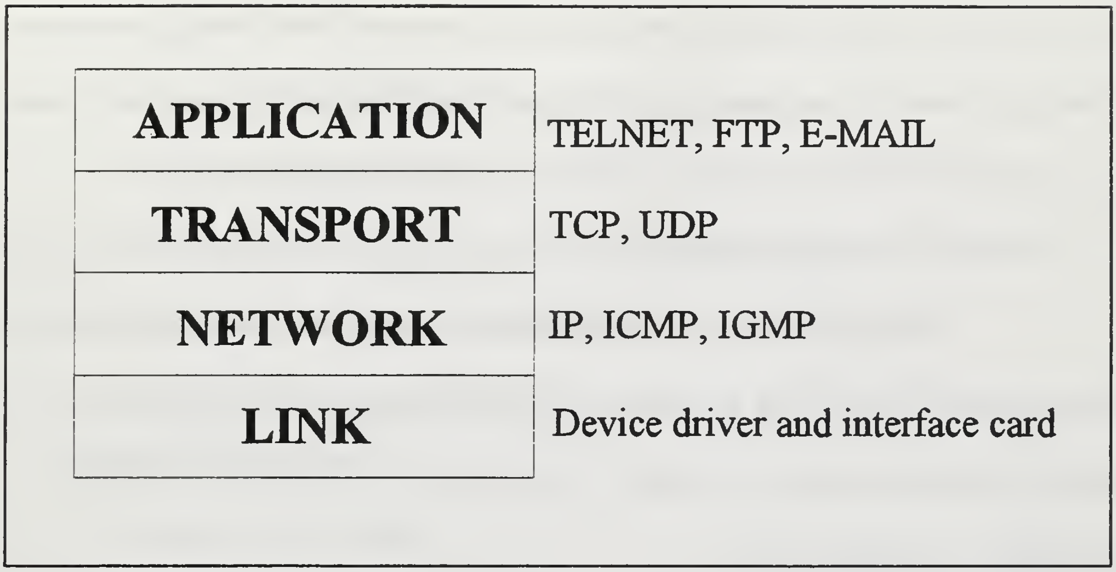

Figure 5.4. Four layers of the TCP/IP protocol suite with example components. From (Stevens, 94).

a. Link Layer

The IP protocol uses the services of the link layer to accomplish the actual transmission along the path. This layer is sometimes called the data-link or the network interface layer and normally includes the device driver in the operating system and the corresponding network interface card in the computer. Together they handle the hardware details of physically interfacing with the cable or whatever type of media is being used.

b. Network Layer

The network layer (sometimes called the Internet layer) handles the movement of packets around the network. Data packets are encapsulated with an IP datagram which contains routing information. This layer is responsible for receiving or ignoring incoming datagrams as appropriate from other hosts. It also handles network error and control messages. Internet Protocol (IP), Internet Control Message Protocol (ICMP) and Internet Group Management Protocol (IGMP) are the protocols that operate at this layer.

c. Transport Layer

The transport layer provides a flow of data between two hosts, for the application layer above. In the standardized TCP/IP model there are currently two different standardized transport protocols: Transmission Control Protocol (TCP) and User Datagram Protocol (UDP).

TCP provides a reliable flow of data between exactly two hosts. It is concerned with tasks such as dividing the data passed to it from the application into appropriately sized packets for the network layer below, acknowledging received packets, and setting timeouts to make certain the other end acknowledges packets that are sent. It is also responsible for reordering datagrams that arrive out of order. Although individual packets are not constrained to follow identical routes, TCP is referred to as a "connection-oriented" protocol since transport layers on corresponding end hosts see a single reliable connection between them.

UDP sends packets of data called datagrams from one host to the other, but there is no guarantee that the datagrams reach the other end. Any desired reliability must be added by the application layer. Thus UDP communications are often called "connectionless" because their is no logical requirement for acknowledgment or retransmission when losses occur.

d. Application Layer

This layer handles the details of the particular application, which is usually a software process. There are many common TCP/IP applications that almost every IP-compatible operating system provides. Several are listed Figure 5.5.

- telnet for remote login
- File Transfer Protocol (ftp)
- Simple Mail Transfer Protocol (SMTP), for electronic mail
- Simple Network Management Protocol (SNMP)

Figure 5.5. Example TCP/IP applications. From (Stevens, 94).

2. OSI Model

The OSI model is a widely referenced network software structuring technique also based on vertical layers. It was developed by the International Standardization Organization (ISO). Like the IP protocols, it provides a framework for defining a set of standards to describe how the communication of computers works. However it is not widely implemented in practice.

Each OSI layer performs a related subset of the functions required to communicate with another system. It relies on the adjacent lower layer to perform more primitive functions and to conceal the details of those functions. Each layer also provides services to the adjacent higher layer. The functions and capabilities expected at each layer are specified in the reference model. The model does not specify however, how this functionality must be implemented. The requirement to interface to adjacent layers typically provides undesirable overhead since direct communication between nonadjacent layers is not permitted. For clarity, a representation of the OSI model mapped to corresponding layers in the TCP/IP model is shown in Figure 5.6. Explanations of each layer follow.

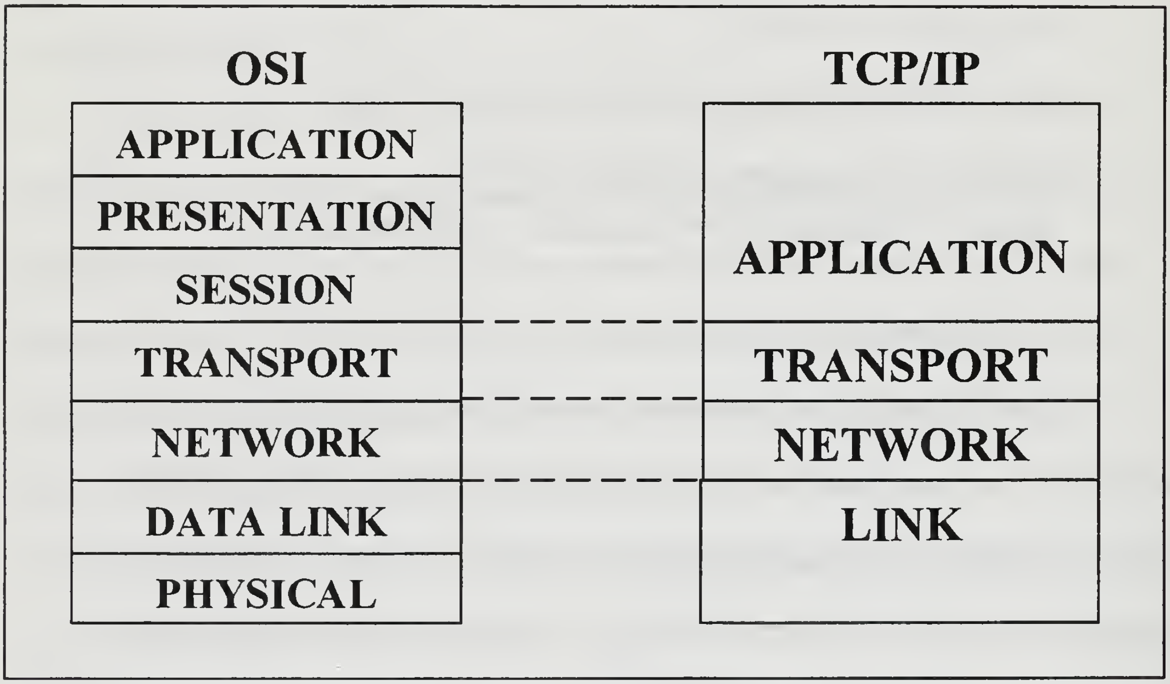

Figure 5.6. Correspondence between OSI and TCP/IP models. From (Brutzman,96).

a. OSI Application Layer

The application layer is responsible for giving user applications access to the network. Examples of application-layer tasks include file transfer, electronic-mail services, and network management. To accomplish its tasks, the OSI application layer passes program requests and data to the OSI presentation layer, which is responsible for encoding the application layer's data in the appropriate form.

b. OSI Presentation Layer

The OSI presentation layer is responsible for presenting information in a manner suitable for the applications or users dealing with the information. Functions such as data conversion, special graphics or character sets, data compression or expansion are carried out at this layer.

c. OSI Session Layer

The OSI session layer is responsible for synchronizing and sequencing the dialog and packets in a network connection. This layer is also responsible for making sure that the connection is maintained until the transmission is complete, and ensuring that appropriate security measures are taken during the connection. Functions defined at the session layer include those for network gateway communications.

d. OSI Transport Layer

This layer is crucial because it sits between the upper layers (which are application dependent) and the lower ones (which are network based). This layer is responsible for providing data transfer at an agreed-upon level of quality, such as transfer at specified transmission speeds and error rates. To ensure delivery, outgoing packets are assigned numbers in sequence. The sequence numbers are included in the packets that are transmitted by lower layers. The corresponding transport layer at the receiving end checks the packet numbers (to make sure all have been delivered) and to put the packet contents into the proper sequence for the recipient. Finally, the transport layer provides services for the session layer above and uses the network layer below it to find a route between source and destination.

e. OSI Network Layer

The OSI network layer is also known as the packet layer. It is responsible for determining addresses or translating from hardware to network addresses. These addresses may be on a local network, or they may refer to networks located elsewhere on an internetwork.

One of the functions of the OSI network layer is to provide capabilities needed to communicate on an internetwork. The layer is also responsible for finding a route between a source and a destination node or between two intermediate devices. It is responsible for establishing and maintaining a logical connection between these two nodes to establish either a logically connectionless or a logically connection-oriented communication.

Data is processed and transmitted using the data-link layer below the network layer. Responsibility for guaranteeing proper delivery of the packets lies with the OSI transport layer, which uses network-layer services.

f. OSI Data Link Layer

This layer reproduces, transmits and receives data packets. The layer provides services for the various protocols at the network layer, and uses the physical layer to transmit or receive material. The OSI data link layer creates packets appropriate for the network architecture being used. Requests and data from the network layer are part of the data in these packets. These packets are passed down to the OSI physical layer.

g. OSI Physical Layer

The OSI physical layer is the lowest layer in the model. This layer gets data packets from the OSI data link layer and converts the contents of these packets into a series of electrical signals that represent 0 and 1 values in a digital transmission. These signals are sent across a transmission medium to the OSI physical layer at the receiving end. At the destination, the corresponding OSI physical layer converts the electrical signals into a series of bit values. These values are grouped into packets and passed up to the local OSI data link layer.

3. ISDN MODEL

ISDN is used for user-to-user communications and for user-to-network communications. The bulk of ISDN protocols deal with the interface between the user site and the network over the D-channel. The protocols dealing with the B-channel are basically transparent to the ISDN user applications.

The TCP/IP protocols primarily deal with network interactions above the data link layer. This means that IP can typically be sent using any data link and physical link protocols. The ISDN model can be mapped to the bottom two layers of the TCP/IP stack (i.e. the Link Layer and Network Layer). ISDN is essentially unconcerned with the

Transport and Application layers of TCP/IP because ISDN deals solely with end-point network access and not with end-to-end routing of Internet traffic between hosts. The Transport and Application Layers deal with connection management and end-to-end host connectivity. Applications on the host machines communicating over the network are expected to provide their own end-to-end services. Otherwise they rely on TCP/IP transport protocols (UDP/TCP) to provide such services. (Tittel/James, 96)

The manner in which IP is transferred over ISDN is specified in (RFC 1356). The Experimental Results chapter in this thesis tests whether IP (in particular multicast IP) can run over the data and physical link of BRI ISDN.

Figure 5.7 shows this comparison between OSI, TCP/IP and ISDN models.

OSI	TCP/IP	ISDN						
Application	Application	End-to-End User Signaling Above ISDN						
Presentation								
Session								
Transport	Transport							
Network	Network	Call Control CCITT I.451	X.25 Packet Level		X.25 Packet Level			Layer 3
Data Link	Link	LAP -D (CCITT I.440,I.441)			X.25 LAP-B			Layer 2
Physical		CCITT I.430, I.431						Layer 1
		Signal	Packet	Telemetry	Circuit Switching	Leased Circuit	Packet Switching	
		D Channel			B Channel			

Figure 5.7. Correlation between OSI, TCP/IP and ISDN models.
After (Tittel/James, 96).

a. ISDN Layer 1

Figure 5.8 lists the functions of ISDN layer 1.

- Encoding of digital data
- Duplex transmission over the B-channel
- Duplex transmission over the D-channel
- Multiplexing of BRI or PRI connections
- Activation and deactivation of the virtual circuit
- Provision of power from NT1 to terminal
- Faulty terminal isolation
- D-channel contention/access

Figure 5.8. ISDN Layer 1 functions. From (Tittel/James, 96).

ISDN Layer 1 describes the physical connections between ISDN devices and the network termination device (NT1). CCITT Recommendation I.430 defines the physical layer specifications for the BRI channel. The PRI physical layer is defined in CCITT Recommendation I.431.

b. ISDN Layer 2

This layer is concerned with the communications between two machines. With ISDN the responsibility for call setup, maintenance and disconnection between two machines lies with the D-channel. For this reason, Link Access Procedures (LAP-D) is concerned mainly with the D-channel. LAP-D is defined in CCITT standards I.440 and I.441.

LAP-D's purpose is to provide two types of service. It must handle multiple terminals on the user-network side of the NT1, and it must be able to support communication between multiple layer 3 protocols operating on the ISDN.

Link Access Protocol-B (LAP-B) is the X.25 layer two protocol. CCITT standards specify that X.25 may be used for packet-switching transmission on the D-channel. X.25 was in existence before ISDN standards and so LAP-B incorporated X.25 in its standard. However there are problems using LAP-B over the D-channel and many authors recommend avoiding use of LAP-B in an ISDN network (Angell, 1996). Essentially this is a hardware design issue of little direct interest to ISDN users.

c. ISDN Layer 3

ISDN Layer 3 is concerned with network functions of addressing, routing and delivery of information. On an ISDN network, the D-channel is designated to perform these functions. This layer deals with signaling procedures established between the user network and the ISDN, call control, and access to and control of supplementary services.[3] This protocol information is carried across the network in LAP-D frames. (Tittel/James, 95)

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[3] Internal network signaling is carried out by out-of-band signaling which is discussed in Chapter IV. Layer 3 signaling discussed here deals with signals carried from the user network or terminal to the ISDN.

CCITT standard I.451 describes call control procedures. X.25 is a protocol suite that defines operations between devices in a packet-switching network. X.25 was in existence before ISDN, and ISDN has incorporated the X.25 standards when dealing with a packet-switching network. Otherwise the ISDN network mainly concerns itself with channel D.

D. ISDN FUNCTIONS NOT DIRECTLY MAPPED TO TCP/IP OR OSI

There are certain requirements for ISDN that do not have clear correspondences within the structure of the TCP/IP or OSI models. The most important of these aspects are listed in Figure 5.9.

- **Multiple Related Protocols:** An example of this is the use of a protocol on the D channel to set up, maintain and terminate a connection on a B channel.
- **Multimedia Calls:** ISDN will allow a call to be set up that allows information flow consisting of multiple quality of service types such as voice, data, facsimile, and control signals.
- **Multipoint Connections:** ISDN allows conference calls (i.e multiple simultaneous callers).

Figure 5.9. ISDN requirements not directly mapped to OSI. From (Stallings, 88).

Leading ISDN manufacturers have been collaborating on new multiple related protocols for bandwidth management. Bandwidth management is needed in order for ISDN to be a technically sound and cost-efficient solution for extending a LAN environment. One B channel provides a 64 Kbps bandwidth. Combining two B channels provides a 128 Kbps bandwidth which is acceptable to adequately perform necessary applications in the LAN environment. By collaborating on protocols, ISDN manufacturers are trying to provide standards which will enable equipment from different vendors to be interoperable. Some protocols have already become an Internet standard, such as Point-To-Point Protocol (PPP) (RFC 1661). Others are only proposed protocols which are under review by the Internet Engineering Task Force (IETF). Those standards and proposed standards which are necessary for an extended LAN environment are discussed in the following sections. The draft specifications for proposed standards are outlined in a series of documents called requests for comment (RFCs).

1. Point-To-Point Protocol (PPP)

Point-To-Point Protocol (PPP) is specified in (RFC 1661). PPP is a standard protocol for transmitting network data over point-to-point links using modems or ISDN links. Each end of the PPP link must send Link Control Protocol (LCP) packets to establish, configure and test the data link during the Link Establishment phase. After the link is established, PPP provides for an Authentication phase before proceeding to the Network-Layer Protocol phase. The current PPP authentication protocols are used to determine identifiers associated with each system connected by the link. (Simpson, 94)

2. Multilink Protocol (MP)

Multilink Protocol (MP) proposes a method for splitting, recombining and sequencing datagrams across multiple logical data links. BRI and PRI ISDN both offer the possibility of opening multiple simultaneous channels between systems, giving users additional bandwidth on demand (for additional cost). By means of a four-byte sequencing header and simple synchronization rules, packets can be split among parallel virtual circuits between ISDN systems in such a way that reordering of packets is minimized. This process of splitting and recombining packets reduces latency and potentially increases the effective maximum receive unit (MRU) packet size. (Sklower, 96)

Once the communication link is established as addressed in the PPP section, the receiving system indicates to the other system that it is capable of combining multiple physical links by responding to multiple authentication identifiers. MP is specified in (RFC 1990) and is on track to becoming a standard.

Using MP, ISDN can provide a virtual link with greater bandwidth than a single B channel (up to 128 Kbps). This higher bandwidth is essential to adequately maintain acceptable data speeds to operate applications across an extended LAN. Applications used in this case study to test whether ISDN provides adequate bandwidth are the new MBone tools (*vat* 4.0b2, *rat* 2.6a2, *vic* 2.8). The new MBone tools only need a bandwidth of up to 128 Kbps to provide adequate voice and video quality for VTC (Wood, 96). MBone and its requirements are addressed later in this chapter.

a. Bonding vs. MP

Many vendors claim that their ISDN equipment has "bonding" capabilities. Bonding allows for the two B channels to be effectively combined into a 128 Kbps transmission. This is usually a hardware bonding which is not a virtual link. It is a proprietary implementation of MP, a non-standard kind of multilink, and interoperability problems are an issue if it is not supported identically by the ISDN equipment at both ends.

The Experimental Results chapter in this thesis tests whether SGI *Indy* computers (which are ISDN capable) can achieve an aggregate 128 Kbps IP data transfer. Since both computers are SGI, there is no way to verify whether the bonding that is performed by the ISDN equipment is a proprietary function or one that satisfies the standard.

3. Compression Control Protocol (CCP)

CCP is a proposed standard which will support adding compression to ISDN communication to generate data transmission speeds up to 512 Kbps on a nominal 128 Kbps BRI line.[4] The 512 Kbps effective rate is a 4:1 ratio over the 128 Kbps which users get when using MP.

Many vendors already have a built-in compression scheme. However if the same (often proprietary) compression scheme is not identically supported by the ISDN equipment at both ends in the same way, compression will not work. The *Indys* used for this case study have a built-in compression scheme.

CCP will allow two devices to determine which type of compression algorithm each supports and then communicate accordingly. Presently vendors have not agreed on a standard because there are still too many compression algorithms to choose among.

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[4] CCP effectiveness is dependent on the type of data being transmitted. Many applications use compression algorithms that produce transmission data which can not be compressed further.

The MBone tools are applications which already use compression schemes to provide low-bandwidth audio and video. Packetized data streams produced by these tools are not affected by the ISDN equipment's built-in compression scheme. Most image formats also include native compression. Therefore, from an Internet user's perspective, CCP only has a noticeable effect on plain text, HTML text and uncompressed data files.

4. Other Proposed Protocols

There are many other proposed protocols for bandwidth management under review by the IETF. Figure 5.10 lists a few of these protocols. RFCs and proposed draft RFCs for these protocols can be reviewed on the Internet. Knowledge of these protocols are not necessary for the purpose of this thesis and therefore will not be addressed further.

- BACP - Bandwidth Allocation Control Protocol gives users a way to add ISDN lines or channels as needed, and drop them when the extra bandwidth is no longer needed. (Richards, 96)
- RSVP - Resource reSerVation Protocol will enable routers to reserve bandwidth for time-sensitive data transmission. (Braden, 96)
- MP+ - Multilink Protocol Plus is an outgowth of MP developed by Ascend Corporation for bonding bearer channels. (RFC 1934)

Figure 5.10. Proposed Standards.

E. IP MULTICAST

IP multicast is a protocol for transmitting IP datagrams from one or more sources to many destinations in a LAN or WAN which use the TCP/IP suite of protocols. The basic service provided by IP multicast only applies to UDP which was briefly discussed earlier in this chapter. In multicast UDP the application sends a single message to one or multiple recipients. The service is unreliable, meaning that erroneous packets are not automatically retransmitted. Thus, there is no guarantee that a given packet reached all intended recipients which belong to the multicast group. This type of service is suitable for the streaming applications usually used on the MBone. The MBone is more concerned with performance than reliability, particularly since automatic retransmission of streamed data is often undesirable. (Macedonia/Brutzman, 94)

There are three fundamental types of addressing mechanisms in the current Internet Protocol (IPv4): unicast, broadcast and multicast. A unicast address is designed to transmit a datagram to a single destination. All packet transfer with a unicast address is inherently point-to-point. If a node wants to send the same information to many destinations using a unicast transport service, it must perform a replicated unicast and send many copies of the data to each destination in turn. The basic facility provided by the TCP protocol is a unicast addressing service. (Stevens, 94)

Broadcasting is sending a single packet addressed to all hosts on a network. This places an unnecessary processing load on hosts that aren't interested in the broadcast. Network segments and hosts can become overloaded with the large amounts of broadcast network traffic. Broadcast addresses are specially reserved IP numbers.

With a multicast service, an application can send one copy of each packet and address it to a group of computers that want to receive it. This technique addresses packets to a group of receivers rather than to a single receiver, and it depends on the network to forward the packets to the networks that need to receive them. For example, a computer can run an audio and video application and each single packet of digitized audio and video information generated by the application will be received by multiple computers. With a multicast group, each node or computer can be physically located anywhere. Packet delivery is provided to hosts that have subscribed to the multicast address of interests.

1. Multicast Backbone (MBone)

The Multicast Backbone (MBone) successfully extends multicast addressing to the global Internet. When using the MBone tools, any host with appropriate multicast-capable software can establish a multicast group (also called a session) by selecting a multicast address and then announcing the group address and session lifetime to the Internet. Hosts are free to join or leave multicast sessions at any time. A single host can be a member of many multicast groups simultaneously. Strictly speaking, a host does not have to be a member of a particular group to send traffic to that group (although membership is usually an application requirement). When the number of members in a multicast group drops to zero, the group is essentially removed from the Internet and the multicast address is freed to be used for another session. (Macedonia/Brutzman, 94)

This thesis uses the MBone tools to test whether ISDN supports native IP multicasting. Failure to support multicast is noncompliance with TCP/IP. If ISDN supports multicasting and two B channels can be effectively combined to provide the necessary bandwidth for MBone, then ISDN can be considered as a technically feasible solution in extending the LAN environment. The Experimental Results chapter tests whether ISDN on SGI *Indy* systems supports channel combination and IP multicasting.

F. ECONOMIC ANALYSIS

ISDN basic rates for the standard configuration of 2B+D in the U.S. are included as Appendix B. Figure 5.11 is an example economic analysis for the NPS STL based on PacBell rates (Pacific Bell, 96). PacBell's tariff is lower than the other RBOCs. These rates (provided to NPS in March, 1996) change periodically. New users installing ISDN outside the PacBell area need to reverify Figure 5.11 price quotes.

This analysis makes several reasonable assumptions, assuming that the user has MBone-compatible Personal Computers (PCs) or workstations equipped with microphones (and optional cameras).[5] Therefore computer hardware costs are not included in this analysis. MBone software is free.

PacBell installation charges are waived if the user commits to use ISDN for more than two years. Monthly administrative costs were determined to be zero for this case because a network administrator is needed regardless of the choice of network. In our case, the NPS STL already has several administrators. If both ends of the system belong to the paying organization, then the setup and monthly user costs need to be multiplied by 2.

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[5] Hardware requirements are addressed in Chapter VI.

Startup Cost:

Line Installation:	
Single Line Installation (Business Service)	$ 71
*ISDN Basic Line Installation (125)	0
**Hardware Costs:	
NT1	200
ISDN PC Adapter Card	500
ISDN Hub (optional, for up to 6 multiple ISDN lines or PRI port)	4,000
Administrative Costs (Network Management)	
Training (PacBell application-oriented and Vendor oriented) (tuition costs range from $500 to $1,000)	0***

* PacBell will waive the 125.00 installation fee if user agrees to 2 years of service
**This analysis assumes user has workstations. Hardware costs are available at *http://www.shoplet.com/hardware/db/905591.html*
*** System administrator did not attend any training. This thesis research provided requisite training.

Recurring Costs:

Monthly Single Line ISDN Usage Fee	$26
Administrative Costs (Network Management)	0
Annual total per line	$312

Total Costs for one Line:	$1,100
Total Costs for ten Lines (STL plan)	7,400*

*The cost was calculated by taking the price to install one PRI line + (monthly charge for PRI line x 12) + ISDN hub. $750+(220x12)+$4,000=$7,400

Figure 5.11. Example ISDN economic analysis for NPS Systems Technology Lab (STL).

G. SUMMARY

The development of standards for ISDN includes the development of protocols for interaction between ISDN users and the network, and for interaction between one ISDN user and another. These protocols can be mapped against the IP and OSI reference models to explain why it is technically feasible to run IP over ISDN. However there are additional requirements for ISDN that are not directly described within the IP and OSI reference models. Unique features of the ISDN reference model and the ISDN protocols are enumerated in detail.

Multicast is an IP standard. Failure to support multicast is noncompliance with TCP/IP. If ISDN is used to extend an IP network, then ISDN needs to support IP multicasting. If multicasting is supported and two B channels can be bonded by using MP, then the MBone tools can be used as a desktop VTC system in an extended LAN environment The technical feasibility of this assumption is tested in the Experimental Results chapter.

VI. ISDN-RELATED HARDWARE

A. INTRODUCTION

The combined voice and data capabilities of ISDN support a broad range of applications. However, unlike traditional POTS phone lines which all work alike, ISDN lines must be specially configured by the phone company to support the user's intended applications. For example, the LAN-extension environment described in Chapter V only supports telecommuting functions which are concerned with IP-compatible data only. Therefore the corresponding ISDN line ordered is a 2B+D, data only line. The configuration setup for this line is different than the configuration for the user who wants simultaneous voice and data traffic or a room-sized VTC application.

The actual ISDN connections for these applications have unique and incompatible specifications which require different CPE equipment. This chapter is concerned with the equipment setup for an extended-LAN environment addressed in Chapter IV.

Section B explains an ISDN topology. It uses reference points to define the communication between the different devices and the parameters for the functional devices. Section C identifies the actual equipment used in this thesis.

B. ISDN WIRING

ISDN is a digital technology which employs essentially the same type of copper wires used for regular telephone service. However the wiring configurations for ISDN operate differently. The Electronic Industries Associations and the Telecommunications

Industry Association standard (EIA/TIA) for wiring analog and ISDN service requires an unshielded twisted-pair (UTP) cable of category 3 or above. The ISDN cable needs to be 33 feet or less from the Network Termination device (NT1) to the ISDN equipment. (Tittle/James, 96)

The demarcation point (DP) is the dividing line between the telephone company's wiring and the premises wiring. This point can occur either inside or outside the building. If the DP is outside, the dividing line is at a junction box. If the DP is on the inside, the dividing line is at a terminal block. From the DP inward, the telephone wiring is the user's responsibility. The demarcation point is also known as the network interface (NI).

ISDN and POTS outlets look exactly alike but differ in the connection jacks: ISDN uses an 8-wire RJ-45 jack and POTS uses a 6-wire RJ-11 jack. Neither ISDN nor POTS uses all available wires. With ISDN only 4 of the 8 pins are used. Most ISDN documentation states that you can use the RJ-11 jack and don't need to install an RJ-45 jack. Such documentation claims that "the telephone company won't tell you this and will charge you for the unnecessary jack" (Leeds, 1996). To avoid connector compatibility problems, this author recommends using the recommended RJ-45 jack. ISDN has too many complex issues. It is safer to use a standard that has been proven to work than to second guess compatibility issues with personally rewired adapter jacks.

In this case study, the user did not have a choice in the line hookup. NPS is a military installation. All telecommunication requests go through NPS Base

Communications personnel, who contract with PacBell for the installation of ISDN lines. Presently there are no technical service employees at NPS Base Communications that are familiar with ISDN. Unfortunately, at the time of the hookup, there were no system administrators present to ask the PacBell serviceman questions.

ISDN circuits are implemented by the provider as two-wire copper circuits from a central office within 3 miles of the user's demarcation point. It should be noted that this 3-mile limit is the biggest barrier to widespread delivery of ISDN service. The standard telephone wiring can only transmit a signal for three miles without putting in repeaters to extend the distance. Repeaters make the delivery of ISDN expensive.

The RJ-45 ISDN interface is also known as a two-wire U interface, which is defined by CCITT as the demarcation point of the two-wire ISDN subscriber loop. The U interface is then connected to an NT1 device. The NT1 represents the boundary to the ISDN network from the end-user side. The NT1 includes the physical and electrical termination functions of ISDN on the customer premises. The physical function of the NT1 device is that it provides an interface between the twisted-pair wires used by the telephone company in the BRI and the eight-wire cables used by ISDN equipment. This is called the S/T interface. The electrical function of the NT1 is to act as the power source for operating the ISDN line.[1] (Leeds, 1996)

Each BRI access has only one NT1 device. A separate S/T reference point in the NT1 device will provide direct multipoint connection of ISDN devices. Multipoint configuration refers to the operation of multiple devices on an ISDN line. These multiple

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[1] Unlike POTS, if there is a power failure, ISDN stops working.

devices include digital phones, digital faxes, and integrated voice/data terminal devices. It is important to note that in order to run multiple devices on one line, all ISDN equipment must support the multipoint protocol. If any equipment only supports point-to-point, then no other device can be used in conjunction with it.

The NT1 can be a stand-alone device or it can be embedded in a specific device. It is important to note that if the NT1 is embedded in a specific device (such as a PC with a remote access adapter card) it will restrict the use of the ISDN connection to that device. In this example, the user will only be able to use the BRI line for that PC, unless the PC has additional ports to connect other ISDN devices. Most documentation recommends using a stand-alone NT1, because as stated above, for each ISDN line there can be only one NT1. A stand-alone NT1 was used in this thesis.

There are two types of devices that can connect to an S/T interface: terminal adapters (TAs) and terminal equipment (TE1). In an ISDN implementation, the TA device is a protocol converter that adapts equipment not designed for ISDN. The TA provides an R reference point, which lets non-ISDN analog serial data terminal devices (such as modems, fax machines, POTS telephones, and routers) to connect to the NT1 device for ISDN service. Devices that require a TA are called TE2 devices. TAs are being phased out because more and more equipment is designed to be ISDN ready (TE1). ISDN venders also market TAs that include the NT1 function as well as support non-ISDN devices (Leeds, 1996). Only one TE1 was connected to the NT1 used in this thesis.

Figure 6.1 shows a simple ISDN hookup. The reference points in Figure VI.1 define the communication between the different devices and the parameters for the functional devices. They are consecutive letters of the alphabet chosen by CCITT to identify a set of standards. This enables vendors and users to refer to their equipment in similar terms.

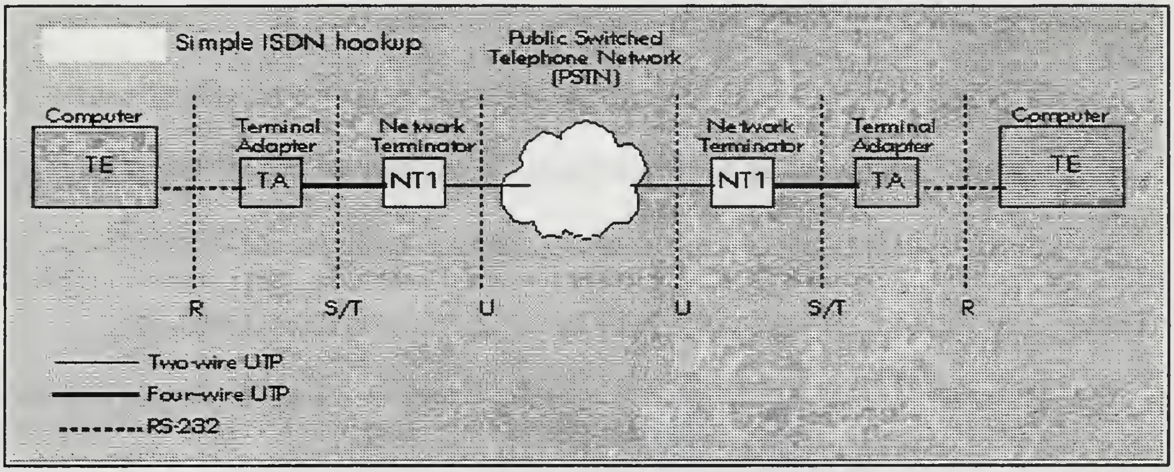

Figure 6.1. Simple ISDN hookup. From (Beckman, 95).

C. IDENTIFYING ISDN APPLICATION EQUIPMENT

User application requirements drives the equipment selection process. The most important factor to consider is interoperability. Every ISDN connection has two ends and the equipment at each end (which may vary) must be compatible for communications to succeed.

If the user is providing the equipment at both ends, buying from a single vendor vastly reduces compatibility problems. Single-source buying isn't always possible, however, and is not an option when using ISDN to connect to an Internet Service Provider (ISP). In such cases, the user can obtain a list of compatible equipment from the

ISP. In this case study, connection to the Internet is made through the NPS connections and the equipment on both ends of the ISDN lines are SGI *Indy* workstations.

Some hardware features such as data compression, bandwidth on demand (BOND) and dial-back security, are proprietary to specific vendors. Others, such as password security and multichannel bonding, have defined standards that are supposed to guarantee interoperability. However, experience has shown that ISDN standards leave room for vendor interpretation. There are web sites which show many users frustrated because of standards that are not truly standards. A user can get this information by doing a web search of ISDN frequently asked questions (FAQs) or the ISDN User's Group. Current links are located on Dan Kegel's ISDN home-page (Kegel, 96).

Each model of ISDN equipment has a different setup using different configuration commands. Vendors of ISDN equipment are trying to make setup easier for the user by having on-line manual pages and CD-ROMs which are already programmed for the setup procedure. However as noted in the Experimental Results chapter, the setup procedures are not always what this author would call user idiot-proof. Even the experienced administrator finds it difficult to interpret the commands of the on-line setup or the instructions of a manual. After many frustrating hours trying to configure the equipment, the user often has to resort to vendor technical representatives for information.

Another important problem diagnosis action it to call the phone company to ensure that the ISDN line is working properly and the phone company ISDN switches are configured properly. This too can be a trying experience because it may take a couple of days for the representative to call the user back. When they do call, technical representatives cannot see or directly diagnose the problem over the phone line. Therefore correcting the problem is sometimes a best-guess effort and finding the solution often becomes a hit-or-miss trial. These issues are painstakingly documented in the Experimental Results chapter.

1. NT1

A Motorola NT1D is the Network Termination device (NT1) that was used for the case study. It costs about $200 and includes the standard two S/T-interface ports. It was purchased through the DoD procurement system as a credit card purchase. Figure 6.2 shows an NT1D.

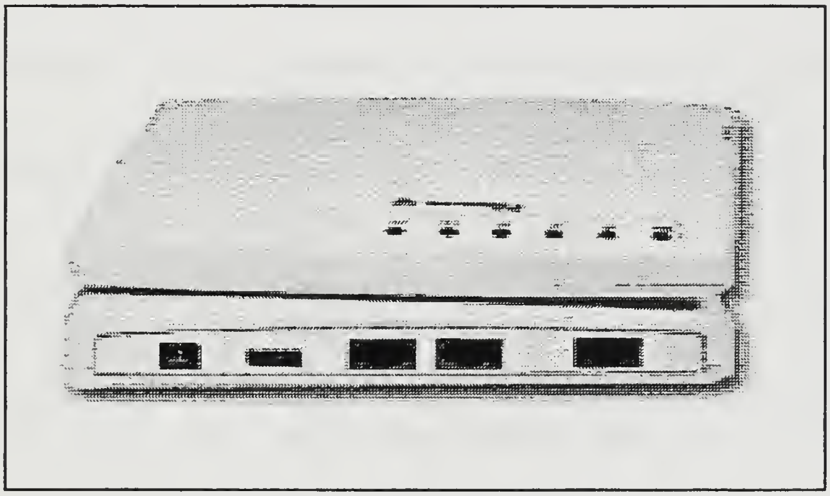

Figure 6.2. Motorola NT1D.

The Motorola NT1D is designed for the ISDN basic rate communication system. As shown in figure 6.1, it installs between the Central Office (CO) U interface and the Customer Premise (CP) S or T interface. Both point-to-point and point-to-multipoint configurations are supported. This case study only used the point-to-point configuration.

There are six light-emitting diodes (LEDs) on an NT1. Each LED indicates that the NT1 is performing a certain function. Figure 6.3 explains the functions of the six LEDs on the front of the NT1. Figure 6.4 shows a closeup snapshot of the rear panel of the Motorola NT1. The rear panel houses (from left to right) the power jack, one four-position dip switch for terminating resistor selection, two jacks for either an S or T interface to the CP equipment, and one U jack for connection to the CO.

LED	DESCRIPTION
SC (Sealing Current)	When on, this LED indicates the ISDN switch has bounced back a termination test voltage from the NT1D.
ACT (Activity)	When on, this LED indicates that a link between the terminal equipment and the ISDN switch at the phone company via the NT1D has been established. If a disruption occurs between the U-interface and the ISDN switch, this LED flickers. If a disruption occurs between the S/T- interface and the Terminal equipment, this LED blinks once per second. If a disruption occurs on both U- and S/T- interfaces, this LED goes off.
LB (Loop Back)	When on, this LED indicates the ISDN switch has sent a 2B+D loopback command to the NT1D.
LP (Local Power)	When on, this LED indicates the local AC power is active.
RP (Remote Power)	When on, this LED indicates the power at the remote site is functional.
RPR (Remote Power Reversed)	When on, this LED indicates the power at the remote site is not functioning properly.

Figure 6.3. Functions of the LEDs on the NT1D. From (Angell, 1995).

Figure 6.4. Closeup snapshot of rear panel of Motorola NT1D.

a. NT1 Hookup

To connect the NT1, the supplied U cable inserts into the U jack on the NT1 and the opposite end connects to the ISDN wall jack. Similar cables are used to connect the S/T jacks to the designated TE1 or the TA (R interface). In this case, the NT1 was connected to an SGI *Indy* workstation which is ISDN capable.

2. Terminal Adapters

There are two types of remote access devices that will connect to a PC: a bus adapter card and a stand-alone unit. The bus adapter cards are cheaper than the stand-alone solution. Bus cards use the PC bus configuration to communicate from the user's PC to the terminal adapter. The cards support Ethernet or serial communication.

A stand-alone ISDN bridge looks like a standard modem and requires a LAN adapter in the PC. A bridge connects separate physical networks into a single logical network that behaves as though it were a single physical network. The PC only communicates via Ethernet to the ISDN bridge. The Ethernet card connects to the ISDN bridge via thin Ethernet coaxial cable or an RJ-45 cable. (Angell, 1995)

The stand-alone ISDN bridge is a TA which connects the R interface to the S/T interface. In this case study, ISDN capable workstations were used which had the bus adapter cards. An R interface was not needed.

3. ISDN-Capable Workstations

Originally the NPS STL ISDN connection plan was to connect an SGI *Indy Presenter* named *baby.stl.nps.navy.mil (baby)* remotely to the graphics lab network in Spanagel Hall via ISDN. SGI *Indy Presenters* always include an ISDN interface. *baby* was connected to an SGI *Indy* workstation named *rambo.cs.nps.navy.mil (rambo)*. *rambo* is hooked up to a different Ethernet LAN as well as to a different ISDN connection.

To avoid sharing conflicts with other students and instructors over *baby*, it was decided half way through the testing to hook-up and configure an SGI *Indy* workstation in the STL for ISDN. The workstation used is a standard *Indy* named *steel.stl.nps.navy.mil (steel)*, also equipped with a video camera and microphone.

4. Video Conferencing Equipment (MBone)

Figure 6.5 shows how two computers can be connected together using ISDN and have a desktop VTC. The only hardware needs for MBone applications is a video camera that sits on top of the PC and a microphone. As stated above, the *Indy* workstations are equipped with a camera and microphone. Video cameras are only needed for sending video, since generating received networked video is performed in the software.

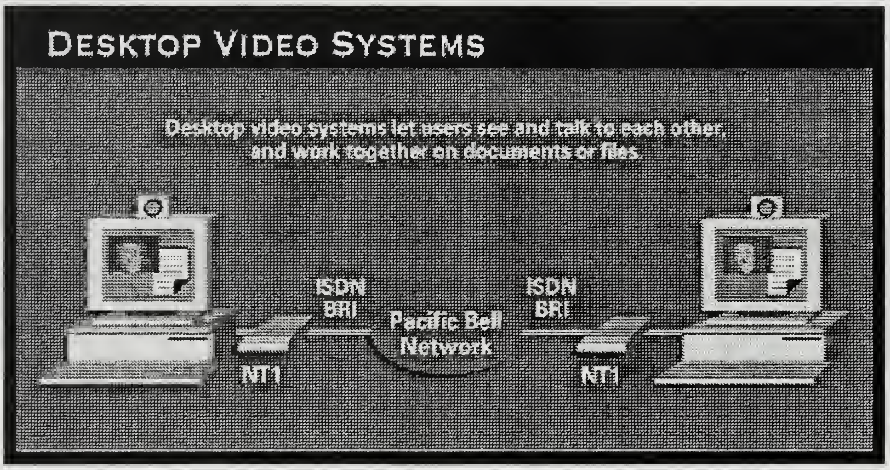

Figure 6.5. Desktop video systems. From (PacBell, 94).

D. SUMMARY

The actual ISDN line connections used for ISDN applications have unique and incompatible specifications which require different equipment. This chapter is concerned with only the equipment needed for the LAN extension environment addressed in Chapter V. It describes hardware considerations for communication between the different devices and the functions of those devices.

VII. EXPERIMENTAL RESULTS

A. INTRODUCTION

The area of focus in this thesis was to determine if BRI ISDN can support TCP/IP protocols, especially bonded channels and native IP multicast. In theory, TCP/IP deals with network interactions above the data link layer of the OSI model. Therefore IP can run over any data link and physical link protocols. ISDN protocols are mainly concerned with the data link and physical link. Standards require that multicasting be capability of an IP network. This chapter tests whether it is technically feasible to perform native IP multicasting over ISDN, so that ISDN is a “true” IP network extension technology.

Section B addresses the initial plan of attack for installing an ISDN line and attempting to run an MBone demonstration. Section C addresses how the workstations were configured to run ISDN. Section D addresses test results once the workstations were configured.

B. MBone DEMONSTRATION

Part of the experimentation was to use ISDN to connect to a host site in France. This test was intended to determine whether the ISDN standards were world-wide or nation-wide. The Fifth Annual World Wide Web Conference was to be held on May 7, 1996 in Paris France. The conference was being transmitted using the MBone. The objective was to telecommute to France and get on the Internet using that connection. If the ISDN standards were just nation-wide, we would telecommute to a local site and get Internet access.

There were two weeks to get a line installed and to test the feasibility of using MBone tools over ISDN. Initially a line was to be installed in the STL in Root Hall at NPS. Base Communications had ten ISDN lines available for data that no one was using. An ISDN jack and line was requested to be installed in the STL in order to be connected to one of the available lines.

The STL had a portable SGI *Indy Presenter* named *baby* that was never previously used for ISDN. The graphics lab in Spanagel Hall at NPS had an *Indy* workstation named *rambo* that was already connected to ISDN as well as being connected to the Ethernet LAN. It was decided to hook *baby* to ISDN to determine if it was ISDN capable and have it communicate via ISDN with *rambo*. Once *baby* was telecommuting with *rambo*, the MBone tools would be tested. Then if everything worked, a point of contact in Paris would be established for a trial run before the conference.

A work request to have PacBell come to NPS and install the jack and line was generated and hand carried through the administrative chain of command. This was done to shorten the wait time in the processing queue and to get NPS Base Communications to make the ISDN line request high priority.

NPS Base Communications was unable to satisfy the request to install a jack and line because of the short time constraint. It would take two-three working days for

PacBell to come in and install the line. There are however other existing ISDN lines at NPS that are used to transmit data. One line was in an office in Spanagel Hall that was unused. The line was connected to an ISDN jack but did not include an NT1. The original work request was modified to read "connect an available ISDN data line in NPS Base Communications to Spanagel Hall, office 402B." NPS Base Communications was able to satisfy this second request.[1]

The MBone demonstration of this conference over ISDN did not take place. This failure was particularly disturbing because it was intended to serve as a backup to the school's primary MBone connectivity. When this primary MBone link went down 10 seconds into the NPS presentation on the distributed panel, no backup ISDN connectivity was available. Rather than NPS discussing future uses of the MBone, NPS demonstrated technical failures before a global audience. This performance is unsatisfactory. (Brutzman, 96a)

The major reason why the MBone demonstration over ISDN did not work was because of the lack of technologically proficient personnel at NPS. Initially the line in Spanagel 402B could not be activated. The system administrator for the STL tested the setup and the ISDN equipment configuration for two days before giving up and asking NPS Base Communications to test the ISDN line. In order to get technical support from

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[1] The first work request eventually had to be rewritten and resubmitted in order to get an ISDN line for the STL for future, related work.

PacBell, Base Communications has to initiate the request which causes additional time delays. It took two days for NPS Base Communications to contact PacBell.[2]

It was explained by NPS Base Communications that the ISDN switch at the Central Office (CO) can determine whether a line is being used or not. It pings the NT1 to verify that it is activated. If there is no NT1 attached to the line or the NT1 is powered off, the ISDN switch will turn the connection off. The office in Spanagel Hall had a line and ISDN jack but was never connected to an NT1. Apparently this caused the CO switch to turn off the line.[3]

NPS Base Communications personnel are not currently knowledgeable about ISDN and therefore thought that the activation of the existing line was an internal job rather than a job for PacBell. Therefore the hook-up of the ISDN line was not properly performed.

Although the window of opportunity was closed for this MBone event, we decided to continue setting up an ISDN line in the STL to determine whether it was technically feasible to use MBone over ISDN. The scope of the investigation was narrowed to include only nation-wide protocol implementations instead of world-wide

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[2] It is noted that the request to Base Communications for assistance was informally done. Normally a work request needs to be generated before Base Communications performs any work. This would have taken an additional 1-2 weeks to route. Base Communications allowed this job to take priority because of the time constraint of the conference and the fact that it was thesis related.

[3] This is Base Communications explanation of the problem with the line. A STL system administrator never got to talk with the technical representatives from PacBell and so this theory was not verified.

protocol implementation. Once ISDN was installed, *baby* would connect remotely to *rambo* to test MBone operability.

When the ISDN line was eventually installed in the STL, there was no prior notification by NPS Base Communications and therefore no STL system administrators were available to ask questions or to watch the installation. This was frustrating because the network administrator's responsibility is to support and maintain new technology and equipment, but they were not given the tools or knowledge with which to do it. No information was received from PacBell or NPS Base Communications explaining the BRI channel transmission capacity (64 Kbps or 56 Kbps), switch type or software used by PacBell. This information is necessary to properly setup the ISDN equipment. These problems are exhaustively documented here because we believe they are commonplace and a frequent impediment to proper ISDN operation.

To avoid sharing conflicts with other students and instructors over *baby,* it was decided to hookup and configure another SGI *Indy* workstation in the STL for ISDN. The workstation is named *steel.stl.nps.navy.mil (steel)*.

C. SETTING UP WORKSTATIONS

1. ISDN User's Guide

SGI *Indy* workstations come with online help manuals called IRIS InSight. The ISDN User's Guide is one such help manual. It provides information about setting up an *Indy* ISDN connection. A copy of this guide is available online at *http://www.ngonet.ee:88/SGI_EndUser/ISDN_UG.*

2. Phone Company Services

The user needs to order 2B + D for circuit-switched data only.[4] The user does not want X.25 (packet-switched data) or voice-related service. Any other switch configuration will not get 2B channels to bond properly.

As mentioned in Chapter IV, the user needs to know which type of switch hardware and switch software the phone company uses. Depending on the type of switch, the user may need a Service Profile Identifier (SPID). This is an alphanumeric string that uniquely identifies the service capabilities of an ISDN terminal. The SPID is an identifier that points to a particular location on the telephone company's CO switch memory where relevant details about the device are stored.

As mentioned earlier, there was no NPS system administrator present to obtain information during the PacBell line installation. Representative documentation was received from the system administrator in Spanagel Hall who set up *rambo* with ISDN. That documentation indicated that PacBell used Custom software which does not require a SPID for setup. Therefore, it did not appear necessary to obtain any information from the phone company.

3. UUCP, PPP and ISDN Software

UUCP, *PPP* and *ISDN* software are all needed for *Indy* ISDN connections and superuser privileges are required to install them on workstations. *UUCP* software is a part of the Irix operating system software but it is not installed by default. *UUCP*, *PPP*

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[4] Various circuit-switch line configurations are addressed in Chapter IV.

and *ISDN* software are located on the main SGI software CD. To install the software on an SGI workstation, see instructions in "Setting up the ISDN software" in IRIS InSight help manuals.

4. Configuration Files

steel is connected to the fiber distributed data interface (FDDI) backbone on campus as well as ISDN. For this case study, *steel* was to represent a user's home computer which would not be connected to a fiber network or any other network. Therefore, *steel* would have to be physically disconnected from the network and the error messages informing the user that the cable was disconnected had to be suppressed. A startup script was created to do this. The script was as follows:

```
/usr/etc/ifconfig xpi0 down
cd /etc/rc2.d
ln -s ../init.d/isdn.no_ethernet s31isdn.no_ethernet
```

(All typed on one line)

It was subsequently decided not to disconnect *steel* from the fiber network because *steel* could not be dedicated only to this case study. The experiment continued using *steel* on two simultaneous networks: FDDI and ISDN.

To set up ISDN there are several additional files to configure. The following configuring process is also found in the online help manual.

a. /etc/hosts File

All names and IP addresses corresponding to remote hosts and local machines are placed in this file because a Domain Name Server (DNS) is not being relied upon. Remote host *rambo* and its address was put in this file as follows:

```
131.120.7.49    rambo.cs.nps.navy.mil    rambo
```

b. /etc/config/isdnd.options File

In this file, the software type which is provided by the telephone company is identified to the ISDN daemon. The ISDN daemon is */usr/etc/isdnd* and is used with Point-to-Point Protocol (PPP) when an Indy is accessing another system over the ISDN line. The file includes several lines of information that tell the user how to edit the file correctly. Each line starts with a pound sign (#) to indicate that the line is a comment. The user removes the pound sign (#) from the line in the file that corresponds to the correct switch software type. In this case, the pound sign was removed from the line:

```
-t 5ESS
```

This command line was chosen because as stated earlier the documentation received from the system administrator in Spanagel Hall indicated switch software was Custom.

Once this is done the ISDN software can be turned on by the root superuser by typing:

```
/etc/chkconfig isdnd on
```

c. /etc/ppp.conf File

For each system, the user must supply three lines of information that include the host name of the system, and the name and password of the user login account on that system. A static network route is also requested using *add_route*. Each entry is as follows:

```
<host name>     send_username=<user name>
                send_passwd=<password>
                add_route
```

Thus for *steel* the */etc/ppp.conf* file read:

```
rambo           send_username=baby
                send_passwd=lrmkam
                add_route
                outdevs=2 (This line will be explained in a later section)
```

The static network route is used when the user wants the datagrams to be routed solely through the ISDN line. The routing daemons are turned off. The routing daemons used on the NPS systems are the programs *routed* and *gated*.

If the user wanted both the ISDN and the fiber network running simultaneously, the routing daemons are configured differently. The add_route line in this file is removed. If the static route and the routing daemon are used at the same time, routing is be disrupted and the remote system will not be reached. A detailed description of these considerations can be found on the online IRIS manual pages.

d. */etc/uucp/Devices File*

It needs to be defined in this file what device files are being used. The format is as follows:

```
ISDN isdn/modem_b1-38400 direct
ISDN isdn/modem_b2-38400 direct
```

e. */etc/uucp/Systems File*

The User's Guide recommends making a backup copy of this file in case a default version is needed in the future. The permissions on the original file need to be changed by the root superuser so the file can be edited. The following information needs to be added for each system in the following format:

```
<Host name> Any ISDN 38400 “” “” ISDNCALL[<rate>]<phone
no>CONNECTED
```

(All typed on one line)

The <Host name> is *rambo*. Any refers to any time to place a call. ISDN refers to the device type. 38400 no longer has any meaning. At one time, 38400 represented transfer speed. Now it is filler input and remains a required entry. The rate refers to the rate at which the connection will transfer data. In this case 56 was used. The line ends with the word CONNECTED. It is important that there is a space between each item in each line. That is, leave a space after Host name, Any, ISDN, 38400, both sets of double quotes, and phone number. The final entry appears as follows:

```
rambo Any ISDN 38400 “” “” ISDNCall[56]2005 CONNECTED
```

5. steel Needs Access To rambo

The last line of *rambo's /etc/ppp.conf* file should read:

```
_ISDN_INCOMING reconfigure
```

This is needed to give *steel* access to *rambo*.

6. Restart

When all editing is complete, the system needs to be restarted so the above changes can be recognized by the operating system kernel.

D. TURNING ON THE ISDN CONNECTION

Once the system is restarted for the configuration file changes to take effect, only the administrator who has superuser privileges can turn on and test the connection. A shell window was opened up and the test began. The administrator tried to make the ISDN connection between *steel* and *rambo* by typing: `ppp -r rambo`. After several seconds, if successful, the connection is established and ready to use. The user sees a message similar to the following when a connection is made:

```
ppp[3001]: rambo IPCP1: ready 131.120.7.116 to 131.120.7.49
```

1. ISDN Connection Fails

The first attempt (as well as numerous other attempts) ended unsuccessfully. The output message above which acknowledges a completed connection was never displayed. To verify that the remote system had accepted the password and was running *ppp*, another shell window was opened and the following command was entered:

`netstat -C`. This command showed the status of the different network ports. The results were unsuccessful and inconsistent. Sometimes ec0 was up and sometimes the ppp0 connection never appeared.[5] A successful report will look something like

```
Name    Mtu     Network          Address
xpi0    1500    131.120.7       131.120.7.49
                                224.0.0.2
                                224.0.0.4
                                224.0.0.1
ec0*
lo0     8304      127           127.0.0.1
ppp0    1500    (pt-to-pt)      131.120.7.116
                                224.0.0.1
```

rambo was pinged from another system that was connected via FDDI. It was determined via FDDI and Ethernet that *rambo* was up. The system administrator for the Graphics Lab in Spanagel Hall was called to ask if the ISDN line on their side was working. It was.

A confidence test on *steel* was then performed to make sure that the problem was not with the connection between the NT1 and the TE1. Information on how to run a confidence test can be found in the InSight User's Guide. The notifier confirmed that the ISDN connection was ready to use and that the problem was not with the CPE or the NT1.

---

[5] The connection is down when a * is displayed after the network port.

Testing continued to try and determine which file on *steel* was not configured properly. Then another shell window was opened and the following command was entered: `ISDNstat`. *ISDNstat* reports the progress of the call. The call to *rambo* was placed again. Both B channels were idle. It showed that B1 channel would dial, connect, disconnect and then be idle. No diagnostic messages were provided during these failures.

Another window was opened and ISDN was stopped and restarted. The commands for this is as follows:

```
/etc/init.d/isdnd stop
/etc/killall ppp
/etc/init.d/isdnd start
```

Because of our lack of experience with ISDN, the system administrators were not confident that the configuration was set up properly. They continued to search for answers within the confines of the ISDN equipment. It never occurred to anyone to check with PacBell on the line itself.

Another test was performed to obtain more error status information. This was done by typing the -d flag after the command `ppp -r rambo.` Additional -d flags produce more information. SGI *Indys* allow up to eight different -d flags to the *ppp* command line to display additional information.[6] A printout of status information is

---

[6] Additional -d flags introduces security problems because passwords are displayed.

attached as Appendix C. The printout was given to the Graphics Lab system administrator in Spanagel Hall to evaluate.

After many weeks of ISDN working periodically and failing without reason, NPS Base Communications was contacted. The supervisor stated that PacBell was not using Custom but 5ESS National ISDN 1 (NI1). SPID numbers were required for configuration of this ISDN software. The supervisor stated that both bearer channels needed a SPID number. If this was true, then */etc/config/isdnd.options* file had to be changed to reflect this software and the SPID numbers. NI1 is the switch software and the command line is:

```
-t NI1 -s <SPID1> -s <SPID2> -n <PN1> -n <PN2>
```

The SPID numbers are the ISDN phone number with 01 at the beginning and 0 at the end. Each B channel has a SPID number. PN numbers are the 7-digit phone numbers. Therefore for the STL ISDN connection, the */etc/config/isdnd.options* file now reads:

```
-t NI1 -s 0165661280 -s 016566128 -n 6566128 -n 6566128
```

Diagnostic messages stated that it could not identify SPID. NPS Base Communications was contacted again and a request was made for PacBell to check the switching software. A Base Communication technician came to Root Hall and checked the line and determined it was working properly. The PacBell representative told NPS Base Communications that the switch for Monterey was actually a 5ESS Custom switch. The configuration was changed back to the original to reflect Custom software.

The ISDN connection continues to work intermittently. It has not been resolved as to what the problem is. The lines were tested by NPS Base Communications and they passed. No errors in transmission were noted. The NT1 was replaced with another NT1 to determine if it was a local hardware failure. The connection came up the first time and failed several times after, eliminating the NT1 as the cause of failure. We still have not identified the cause of these intermittent ISDN line failures.

2. Testing MP

The *Indy* supports a nonstandard method for optimizing connection speed and does not use the MP standard. In order to bond two B channels, the */etc/ppp.conf* file needs to be amended. The following line needs to be added: `outdevs = 2.` This command sets the maximum number of parallel serial lines that will be used.

When an ISDN connection between *rambo* and *steel* was made successfully, transmission speeds were tested. This test simulated remote users downloading files from their network at work. A new shell window was created and *ISDNstat* was run to get the status of the two B channels.

Initially the *ISDNstat* window only showed the B1 channel connected and the B2 channel idle. A 1.2 Megabyte (MB) uncompressed executable file was transferred from *steel* to *rambo*. *ISDNstat* window showed that the B1 channel was transmitting at 54-56 Kbps. The file was transmitted again using *ftp*. *ftp* showed that the transmission was closer to 85 Kbps. If it were not for the *ISDNstat* window, a user will likely think 2 channels are connected because of the fast transfer time (>56 Kbps). In reality *ppp* software has a built-in compression algorithm which compressed the file on-the-fly. The debugging script shows that on-the-fly compression is taking place rather than bonding two channels. The test was done two more times and the results were consistent with the first. This test therefore showed that an effective throughput of 85 Kbps was possible on a single B channel.

The system administrator from the STL in Root Hall contacted the administrator in Spanagel Hall about the two B channels not bonding. Because NPS has a maintenance agreement with SGI which identifies one point of contact for all of NPS dealing with SGI equipment, the administrator in Spanagel Hall is the only individual who can request technical assistance from SGI. The inexperienced ISDN administrator from STL has to explain the problem to the inexperienced ISDN administrator in Spanagel Hall who in turn will explain it to the SGI technical representative. Theoretically a solution is provided. In practice this process is time consuming and inefficient. Following SGI technical support recommendations, an SGI operating system software patch was installed that fixed the bonding problem (SGI Irix 5.3 patch 841). Both B channels then connected and similar throughput tests were performed as before. A 3.7 MB uncompressed executable file was transferred from *steel* to *rambo*. The *ISDNstat* window showed that both B channels were connected and that they were transmitting 110 Kbps. The *ftp* command showed that the effective transfer throughput was approximately 164 Kbps. Again the faster-than-maximum speed was due to the on-the-fly compression/decompression in the *ppp* software.

The next step was to precompress the file so that there would be no compression in the transmission. The 3.7 MB executable file was compressed to a 1.2 MB file. The

ISDNstat displayed that each channel was transmitting at 54-56 Kbps. The results were again verified by using the *ftp* command, which recorded an effective throughput of 105 Kbps which corroborated what *ISDNstat* was reporting and confirmed that further on-the-fly compression was infeasible.

3. MBone Testing

Many issues came up when trying to perform multicasting across ISDN. The first issue was creating a tunnel from *rambo* to *steel*. The multicast routing daemon *mrouted* insists that there be more than one virtual interface (vif) before it runs. A vif is either a real physical interface or an encapsulated multicast tunnel. Otherwise *mrouted* can only send the multicast packets out on the same interface as they came in on. *mrouted* is just like a regular router, it takes packets from one interface and sends them out on another interface.

The problem is that the ppp0 interface doesn't come up or even exist until *ppp* runs. Setting up the *ppp* "interface" is one of the things that the *ppp* command does. Therefore, a vif does not exist prior to *ppp* running. The pre-tunnel error message is Appendix D. The solution to this problem was to add a tunnel. The only thing this did was add a vif which allowed *mrouted* to run.

Another multicast issue concerned routing. *steel* is dual-homed with FDDI which has multicast on it. When the multicast tools were run, the session directory came up on the fiber connection and not on the ISDN. We did not want to change the routing daemons (*gated and routed*) because we were not familiar with ISDN and did not want the ISDN line to fail. Therefore, in order to test multicast running across ISDN and not fiber, *steel* would have to be disconnected from the fiber backbone. We did not want to disconnect *steel* (for other reasons) so it was decided to use *baby* for this part of the test.

A session directory (*sdr*) was established on *baby*. *rambo* could not see the advertised session. The audio and video tools (*vic and vat*) were used. Nothing appeared on *rambo's* monitor, but *ISDNStat* indicated that the two B channels were connected and that *rambo* was receiving data at 110 Kbps.

It was concluded that the ISDN line was configured correctly and that it was transmitting and receiving properly. The reason why the session directory was not being advertised on the Internet must be due to an MBone configuration problem which was above the level of the system administrator.

Technical support at SGI reported that there is a bug in the ppp software. Therefore, the *ppp* software does not support multicasting. This information is contrary to what a user from the MBone User's list had reported. The user said that he is using SGI with Ascend products to run MBone successfully. It is possible that this original user employed a unicast tunnel for MBone connectivity rather then passing native multicast IP packets.

E. SUMMARY

This chapter discusses the tortured methodology of how the STL in Root Hall got an ISDN line. It discusses the setup of the hardware and software. It also discusses the results of the ISDN multicast experiments and possible reasons why these experiments failed. The results of the experiment determined that SGI *Indys* have a proprietary solution to MP and if the machines at each end of the ISDN connection are *Indys*, then speeds of over 110 Kbps (without compression) can be achieved. Native multicast support was not successfully demonstrated. ISDN line reliability is intermittent despite exhaustive troubleshooting.

This chapter also documents the frustrations of a proficient system administrator who is inexperienced with ISDN technology and has no available means to get timely, accurate or consistent answers to questions dealing with this new technology. We believe that such difficulties are common based on widespread unfamiliarity with ISDN.

ISDN is still point-to-point. Multicasting with ISDN appears to be unsupported, at least by SGI hardware and software. The technical representatives for the ISDN equipment claim to have bugs in their *ppp* software that prevents it from performing multicasting. However some MBone users claim it can be done (Appendix E).

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

Installing and using a new technology can become quite an arduous task, especially if a new user does not have a technical background. Section B discusses the issues surrounding the failure of extending LAN connectivity using ISDN. Section C presents the results of this case study. Section D discusses recommendations to resolve these issues. Section E presents recommendations for future work.

B. INSTALLATION ISSUES

It is difficult to obtain technical help because ISDN support crosses too many organizational boundaries. PacBell sells the user the ISDN line. The technician that installs the line may not know anything about the technology itself except how to install the line and how to test that it is connected. The information about the technology is obtained from the salesperson who is quoting from the media literature (which is not correct).[1] No confirmation of PacBell's ISDN equipment and specifications is performed.

---

[1] We called PacBell and talked to a sales representative who said that their ISDN was 2B+D and that the B channels were capable of speeds up to 64 Kbps. When asked about the switch software, she didn't know what we were talking about. She put us on hold for five minutes and came back and said the software was National ISDN and not Custom. NPS Base Communications spoke with their PacBell technical representative who said that all their switches in Monterey were Custom.

Another organizational boundary is the vendor of the NT1. This technician needs to know how the NT1 works with the TE1 or TE2 (which might be yet another vendor). The technician also needs to know how the NT1 works with the ISDN line (U interface).

The next organizational boundary is the vendor of the TE1. This is not necessarily the same vendor as the NT1. The technician's responsibility is to know how the software configuration works with the CO switch and the interaction with the NT1.

Given the many problems reported in the Experimental Results chapter, each organizational entity was quick to point fingers at the other. Both PacBell and NPS Base Communications questioned whether the *ppp* software was configured properly. Hardware vendors of the equipment blamed problems on the switch software. The end result is that the user does not receive timely technical help which exacerbates the problem. We expect that most sites would have cancelled the entire connection. We are persevering to continue testing this technology despite the fact that many problems (including line reliability) are unresolved.

Another issue which created a problem in this case study is the organizational structure of NPS and interaction between the individual departments of the organization. NPS Base Communication is a tenant command. They are responsible for all communications within the NPS campus. When a user puts in a work request to Base Communications, it is prioritized based on work for other users within this organization. The job request is considered closed once the work is performed and the line is installed. If the user is having problems getting that line to work, another work request is generated to have the line tested. Again, this new work request is prioritized based on other work of other users. Satisfactory testing must be a condition for completion of work.

Suprisingly, the user who is using the technology is not considered the customer of the service provider. NPS Base Communications is the official customer. Therefore, the user cannot acquire technical help directly from PacBell. The request for technical help has to be initiated through NPS Base Communications.[2] This situation is unsatisfactory.

Getting technical help from vendors about ISDN equipment is also a complex issue. The maintenance agreement for SGI equipment has one point of contact for the entire school. This individual is outside the department requesting the technical help. This causes a problem because a second party gets involved who relays the information to the vendor. Sometimes the detailed complexity of the issue gets lost in the translation. This causes additional problems and compounds the difficulties experienced.

This experiment attempted to connect a workstation within Root Hall to another workstation outside of the boundaries of Root Hall. This was the simplest possible realistic test we could devise. However this meant getting another system administrator involved. This can cause a problem because an agreement has to made prior to the experiment to make the project a responsibility for both system administrators. Often projects that are not the responsibility of both departments, get pushed to the end of the job priority list.

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[2] Base Communications at the time of this writing did not have a technician experienced with ISDN. ISDN training is planned for one technician. Additional training for a second individual is recommended.

When doing a technical thesis, the student has to rely on the system administrator of that department for assistance. The system administrator is the superuser for the network and is the only one who can make changes to the network. This was an issue in this case study because there were many students who needed administrator assistance. The administrator has other duties and responsibilities and it becomes very difficult to schedule priorities. The problem is compounded when crossing organizational boundaries because now the student is dependant on two system administrators and not one. Frequent coordination and patience are essential.

C. EXPERIMENTAL RESULTS

It was experimentally verified that ISDN provides a bandwidth up to 112 Kbps. However it was not experimentally confirmed whether the switch supports a full 128 Kbps (2 B channels at 64 Kbps each). It appears that our link supports 112 Kbps (2 B channels at 56 Kbps each). Additionally it was determined that ISDN is not a completely reliable technology because the line continues to fail and diagnostic efforts have been inconclusive.

All tests to determine whether ISDN supports native IP multicasting were negative. An SGI technical representative said that there is a bug in the *ppp* software which causes their ISDN solution to not support multicasting. However an individual from the MBone Users Group stated that he uses SGIs with Ascend products and it supports multicasting. His solution and others are attached as Appendix E. Their results each use unicast tunnels over ISDN to provide multicast at each end. This is consistent with the results found in this thesis.

D. RECOMMENDATIONS FOR IMMEDIATE ACTION

When dealing with a new technology, one person should be in charge of the whole process. The individual should be responsible for buying the phone lines, buying the ISDN equipment and having superuser privileges on both ends of the link. Crossing organizational boundaries only creates problems. If NPS Base Communications is responsible for all communication technology, then their technicians need to be properly trained and capable of answering user's questions. NPS Base Communications needs to obtain documentation from the ISDN service provider pertaining to the information necessary to make the ISDN equipment compatible with the service provider's equipment. All installations (regardless of technology) should be coordinated prior to the setup date in order to have all responsible individuals present so that questions can be answered. NPS Base Communications must not consider a work request closed unless the technology is working properly. We recommend that NPS Base Communications correct these problems.

To achieve success using ISDN, the responsible individual should choose an ISDN solution with the largest market share, or contract a consultant to buy an interoperable package. This consultant is a liaison between the ISDN service provider, hardware and software providers. The consultant is responsible for maintenance and training support as well as a working product. We recommend training two NPS technical staff members to become as proficient as an ISDN consultant in these areas.

More system administrators need to be employed if assisting students with thesis work is a priority. There are too many students with technical theses and too many other user requirements that need the support of three STL system administrators in Root Hall. More administrators are needed.[3]

A visit to the local PacBell office, visual inspection of the ISDN switching equipment and dialog with the cognizant technical expert will likely resolve many of these open issues. Of particular interest is the means by which PacBell diagnoses line problems.

E. RECOMMENDATIONS FOR FUTURE WORK

When the issues of reliability, capacity and multicast compatibility are resolved, ISDN needs to be evaluated again to determine if it is a viable solution to extending LAN connectivity. Specifically, ISDN needs to be tested across different operating system platforms to determine interoperability especially when dealing with MP. National and global ISDN standards still need to be tested to also determine interoperability issues. ISDN needs to be tested for long distance and international telecommuting. The final issue is multicasting. Although this thesis successfully demonstrated IP over ISDN, multicast usability needs to be verified. This includes remote LAN monitoring from home to include network monitoring pages (Edwards, 96) (Erdogan, 96). Once this is successfully accomplished, it is recommended that STL purchase the ISDN technology and ISDN equipment for system administrative security reasons as well as to test telecommuting effectiveness.

---

[3] Further hiring actions are in progress to correct this situation.

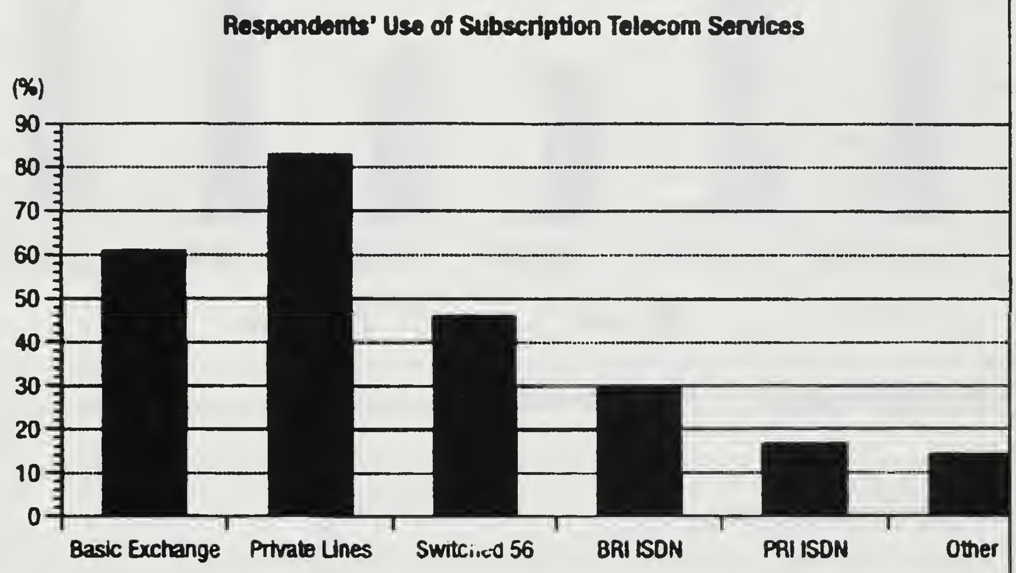
New technologies, need to be evaluated after they enter the marketplace to verify that the technology does everything that the specifications say it does. Information Technology managers need to carefully test products and analyze them thoroughly before making a decision to use it. Buying into media hype and marketing promises will often pull the manager in the wrong direction and possibly cost more money. It is the responsibility of the Information Technology manager to examine new technologies and find the one that best suits the organizations needs, infrastructure and future plans.

F. CONCLUSION

Although this experiment to test ISDN was only partially successful, there were many technical and managerial lessons learned which can be taken away from this case study. DoD must make a concerted effort to evaluate both ongoing and future programs which will implement new technology in order to ensure that the technology increases mission capability in the most beneficial and cost effective manner. Information Technology managers have a responsibility to make intelligent recommendations based on fact and not media hype. Finally, ISDN capabilities have progressed since the three fatal showstoppers identified in (Bigelow, 96). The corrections are not yet complete however. We remain optimistic that ISDN will mature into a data link technology capable of effectively extending Internet-compatable LAN connectivity.

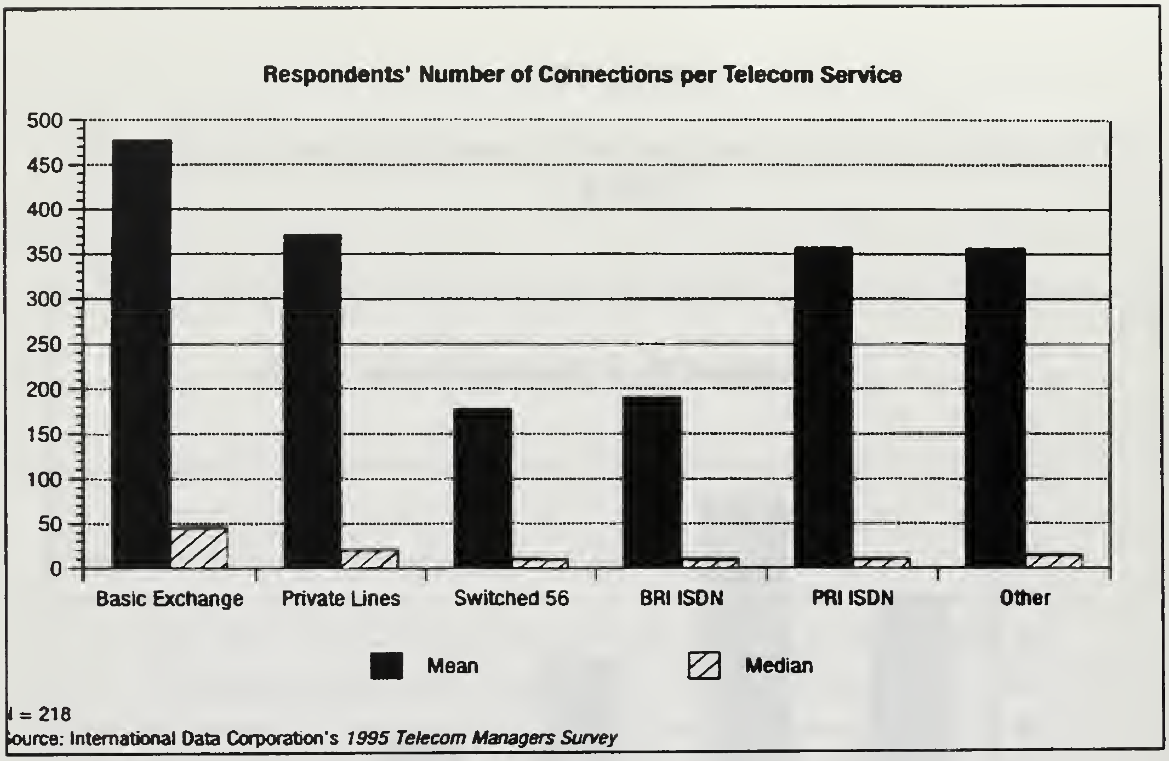
APPENDIX A

INTENATIONAL DATA CORPORATION'S 1995 TELECOM MANAGERS SURVEY



N = 218

Source: International Data Corporation's *1995 Telecom Managers Survey*



= 218

ource: International Data Corporation's *1995 Telecom Managers Survey*

From (Shapiro/Robertson, 95).

APPENDIX B

ISDN BASIC RATES IN THE UNITED STATES

Ameritech

Service	Monthly	Installation	Minutes Included	Per Add'l Minute
Illinois Residential	28.19	135.00		local rates
Michigan Residential	33.51	122.00		local rates
Ohio Residential	32.20	116.50		local rates
Wisconsin Residential	30.90	113.05		local rates
Illinois Business	33.60	132.35		local rates
Michigan Business	37.46	147.00		local rates
Ohio Business	40.60	129.35		local rates
Wisconsin Business	37.00	100.65		local rates

Bell Atlantic

Business ISDN	41.88	125.00		.02/.01+
Residential	34.00	125.00		.02/.01+

Available at *http://www.xmission.com/isdncomp.html*

NYNEX

Service	Monthly	Installation	Minutes Included	Per Add'l Minute
Residential	28.35	57.57		local rate

Pacific Bell

ISDN	24.82	70.75*		local rate

Southwestern Bell

10 Hours	45.50	52.25*	600	.04
80 Hours	63.50	52.25*	4800	.02

US West

Arizona	69.00	110.00	1200	.02
Colorado	60.00	67.00	unlimited	
Oregon	69.00	110.00	1200	.03
Washington	35.00	85.00	0	.04/.015++
Washington	50.00	85.00	2400	.04/.015++
Washington	63.00	85.00	unlimited	

Utah (proposed)

Basic	39.00	110.00	0	.03
200 Hour	68.00	110.00	12000	.03
Flat	184.00	110.00	unlimited	

*larger installation fee waived with minimum service
+day/night
++first minute/additional minutes

Available at *http://www.xmission.com/isdncomp.html*

APPENDIX C

DEBUGGING SCRIPT FOR ISDN PPP SOFTWARE OUTPUT

```
ppp[1666]: rambo IPCP2: Req-Sent(6)->Starting(1)
ppp[1666]: rambo LCP2: send Configure-Request ID=0xf1
ppp[1666]: rambo LCP2: magic=0x6907c18f
ppp[1666]: rambo LCP2: receive compressed protocol field
ppp[1666]: rambo 2: send 0xc bytes: index=11 proto=0xc021 01
           f1 00 0c 05 06 69 C
ppp[1666]: rambo LCP2: send Configure-ACK ID=0x7a
ppp[1666]: rambo 2: send 0x16 bytes: index=11 proto=0xc021
           02 7a 00 16 01 04 05
ppp[1666]: rambo LCP2: Opened(9)->Ack-Sent(8)
ppp[1666]: rambo 2: read 0xc bytes: proto=0xc021 02 f1 00 0c
           05 06 69 07 c1 8f C
ppp[1666]: rambo LCP2: receive Configure-ACK ID=0xf1
ppp[1666]: rambo LCP2: event RCA
ppp[1666]: rambo LCP2: action TLU
ppp[1666]: rambo LCP2: MTU=1500 MRU=1500 TOS
ppp[1666]: rambo LCP2: my magic=0x6907c18f,his=0x6907991f
           sync
ppp[1666]: rambo 2: entering Authenticate Phase
ppp[1666]: rambo AUTH2: will send PAP requests but receive
           no authentication
```

```
ppp[1666]: rambo AUTH2: send PAP request ID=0x89
ppp[1666]: rambo 2: send 0x11 bytes: index=11 proto=0xc023
           01 89 00 11 04 "baby’)
ppp[1666]: rambo LCP2: Ack-Sent(8)->Opened(9)
ppp[1666]: rambo 2: read 0x10 bytes: proto=0x8021 01 05 00
           10 02 06 00 2d 10 00
ppp[1666]: rambo IPCP2: discard Configure-Request because in
           Authenticate, not
ppp[1666]: rambo 2: read 0x11 bytes: proto=0xc023 02 89 00
           11 0c "why is this?"
ppp[1666]: rambo AUTH2: receive PAP Ack ID=0x89 containing
          "why is this?"
ppp[1666]: rambo 2: entering Network Phase
ppp[1666]: rambo LCP2: set sync, acomp=0, pcomp=0,
           rx_ACCM=0, tx=0,pad=0
ppp[1666]: rambo IPCP2: event Up
ppp[1666]: rambo IPCP2: send Configure-Request ID=0xda
ppp[1666]: rambo IPCP2: 16 slot VJ compression without
           compressed slot IDs
ppp[1666]: rambo IPCP2: ADDR our address 131.120.7.116
ppp[1666]: rambo 2: send 0x10 bytes: index=11 proto=0x8021
           01 da 00 10 02 06 00
ppp[1666]: rambo IPCP2: Starting(1)->Req-Sent(6)
ppp[1666]: rambo 2: read 0x10 bytes: proto=0x8021 02 da 00
           10 02 06 00 2d 0f 00
```

```
ppp[1666]: rambo IPCP2: receive Configure-Ack ID=0xda
ppp[1666]: rambo IPCP2: event RCA
ppp[1666]: rambo IPCP2: Req-Sent(6)->Ack-Rcvd(7)
ppp[1666]: rambo IPCP2: event TO+ #0
ppp[1666]: rambo IPCP2: send Configure-Request ID=0xdb
ppp[1666]: rambo IPCP2: 16 slot VJ compression without
           compressed slot IDs
ppp[1666]: rambo IPCP2: ADDR our address 131.120.7.116
ppp[1666]: rambo 2: send 0x10 bytes: index=11 proto=0x8021
           01 db 00 10 02 06 00
ppp[1666]: rambo IPCP2: Ack-Rcvd(7)->Req-Sent(6)
ppp[1666]: rambo 2: read 0x10 bytes: proto=0x8021 02 db 00
           10 02 06 00 2d 0f 00
ppp[1666]: rambo IPCP2: receive Configure-Ack ID=0xdb
ppp[1666]: rambo IPCP2: event RCA
ppp[1666]: rambo IPCP2: Req-Sent(6)->Ack-Rcvd(7)
ppp[1666]: rambo IPCP2: event TO+ #0
ppp[1666]: rambo IPCP2: send Configure-Request ID=0xdc
ppp[1666]: rambo IPCP2: 16 slot VJ compression without
           compressed slot Ids
ppp[1666]: rambo IPCP2: ADDR our address 131.120.7.116
ppp[1666]: rambo 2: send 0x10 bytes: index=11 proto=0x8021
           01 dc 00 10 02 06 00
ppp[1666]: rambo IPCP2: Ack-Rcvd(7)->Req-Sent(6)
ppp[1666]: rambo 2: read 0x10 bytes: proto=0x8021 02 dc 00
```

```
            10 02 06 00 2d 0f 00
ppp[1666]: rambo IPCP2: receive Configure-Ack ID=0xdc
ppp[1666]: rambo IPCP2: event RCA
ppp[1666]: rambo IPCP2: Req-Sent(6)->Ack-Rcvd(7)
ppp[1666]: rambo 2: read 0x10 bytes: proto=0x8021 01 06 00
            10 02 06 00 2d 10 00
ppp[1666]: rambo IPCP2: receive Configure-Request ID=0x6
ppp[1666]: rambo IPCP2: accept 17 slot VJ header compression
            (but use 16) wit
ppp[1666]: rambo IPCP2: accept its address 131.120.7.49 from
            ADDR Request
ppp[1666]: rambo IPCP2: event RCR+
ppp[1666]: rambo IPCP2: send Configure-ACK ID=0x6
ppp[1666]: rambo 2: send 0x10 bytes: index=11 proto=0x8021
            02 06 00 10 02 06 00
ppp[1666]: rambo IPCP2: action TLU
ppp[1666]: rambo IPCP2: Ack-Rcvd(7)->Opened(9)
ppp[1666]: rambo IPCP2: ready 131.120.7.116 to 131.120.7.49,
            rx_vj_comp=y,tx=y r
ppp[1666]: rambo LCP2: set sync, acomp=0, pcomp=0,
            rx_ACCM=0, tx=0,pad=0
ppp[1666]: rambo CCP2: event Open
ppp[1666]: rambo CCP2: action TLS
ppp[1666]: rambo CCP2: Initial(0)->Starting(1)
ppp[1666]: rambo CCP2: event Up
```

```
ppp[1666]: rambo CCP2: send Configure-Request ID=0xe3 for 12
           bit BSD Compress a
ppp[1666]: rambo 2: send 0x9 bytes: index=11 proto=0x80fd 01
           e3 00 09 15 03 2c 0
ppp[1666]:rambo CCP2: Starting(1)->Req-Sent(6)
ppp[1666]: rambo 2: read 0x7 bytes: proto=0x80fd 01 46 00 07
           15 03 2c
ppp[1666]: rambo CCP2: receive Configure-Request ID=0 ~46
ppp[1666]: rambo CCP2: turn off TX compression
ppp[1666]: rambo CCP2: accept 12 bit BSD compression
ppp[1666]: rambo CCP2: event RCR+
ppp[1666]: rambo CCP2: send Configure-ACK ID=0x46
ppp[1666]: rambo 2: send 0x7 bytes: index=11 proto=0x80fd 02
           46 00 07 15 03 2c
ppp[1666]: rambo CCP2: turn on/reset TX 12 bit BSD Compress
ppp[1666]: rambo CCP2: Req-Sent(6)->Ack-Sent(8)
ppp[1666]: rambo 2: read 0x7 bytes: proto=0x80fd 02 e3 00 07
           15 03 2c
ppp[1666]: rambo CCP2: receive Configure-ACK ID=0xe3
ppp[1666]: rambo CCP2: turn on/reset RX 12 bit BSD Compress
ppp[1666]: rambo CCP2: event RCA
ppp[1666]: rambo CCP2: action TLU
ppp[1666]: rambo CCP2: Ack-Sent(8)->Opened(9)
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
```

```
ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: moderate

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: busy

ppp[1666]: rambo: TCP/IP activity: moderate

ppp[1666]: rambo 2: read 0x4 bytes: proto=0x80fd 0e 47 00 04

ppp[1666]: rambo CCP2: receive Reset-Request ID=0x47

ppp[1666]: rambo CCP2: send Reset-Ack ID=0x47

ppp[1666]: rambo 2: send 0x4 bytes: index=11 proto=0x80fd 0f
           47 00 04

ppp[1666]: rambo CCP2: turn on/reset TX 12 bit B5D Compress

ppp[1666]: rambo 2: read 0x4 bytes: proto=0x80fd 0e 48 00 04

ppp[1666]: rambo CCP2: receive Reset-Request ID=0x48

ppp[1666]: rambo CCP2: send Reset-Ack ID=0x48
```

```
ppp[1666]: rambo 2: send Ox4 bytes: index=11 proto=Ox80fd Of
           48 00 04
ppp[1666]: rambo CCP2: turn on/reset TX 12 bit BSD Compress
ppp[1666]: rambo: TCP/IP activity: low
ppp[1666]: rambo: TCP/IP activity: low
ppp[1666]: rambo: TCP/IP activity: moderate
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: busy
ppp[1666]: rambo: TCP/IP activity: moderate
ppp[1666]: rambo 2: inactivity timeout; /dev/isdn/modem_b2
ppp[1666]: rambo LCP2: event Close
ppp[1666]: rambo LCP2: send Terminate-Request ID=Oxf2
           "inactivity timeout"
ppp[1666]: rambo 2: send Ox16 bytes: index=11 proto=Oxc021
           05 f2 00 16 "inactivi
ppp[1666]: rambo LCP2: action TLD
ppp[1666]: rambo IPCP2: event Down
ppp[1666]: rambo IPCP2: action TLD
ppp[1666]: rambo IPCP2: Opened(9)->Starting(1)
```

```
ppp[1666]: rambo CCP2: event Down
ppp[1666]: rambo CCP2: action TLD
ppp[1666]: rambo CCP2: Opened(9)->Starting(1)
ppp[1666]: rambo LCP2: Opened(9)->Closing(4)
ppp[1666]: rambo 2: entering Terminate Phase
ppp[1666]: rambo 2: read 0x16 bytes: proto=0xc021 06 f2 00
           16 "inactivity timeo~
ppp[1666]: rambo LCP2: receive Terminate-Ack: 06 f2 00 16
           "inactivity timeout"
ppp[1666]: rambo LCP2: event RTA
ppp[1666]: rambo LCP2: action TLF
ppp[1666]: rambo 2: entering Dead Phase
ppp[1666]: rambo: Closing(4)->Initial(0)
ppp[1666]: rambo: TCP/IP activity: low
ppp[1666]: rambo: TCP/IP activity: low
ppp[1666]: rambo 1: line off:
ppp[1666]: rambo 1: /dev/isdn/modem_bl off
ppp[1666]: + route delete default 131.120.7.49
ppp[1666]: delete net default: gateway 131.120.7.49
ppp[1666]: rambo: exiting with 0
```

APPENDIX D

DEBUGGING SCRIPT FOR PRE-TUNNEL ERROR MESSAGE

```
rambo 1# /uer/etc/mrouted -d
debug level 2
11:26:01.511 mrouted version 3.8
11:26:01.633 Getting vifs from kernel interfaces
11:26:01.634 installing ec0 (131.120.7.49 on subnet
             131.120.7/24) as vif #0 - ra
11:26:01.635 Getting vifs from /etc/mrouted.conf
11:26:01.677 can’t forward: only one enabled vif
                            AAAAAAAAAAAAAAAAAAAA
```

APPENDIX E

E-MAIL FROM MBONE USERS

Date: Thu, 31 Aug 1995 09:44:11 PDT

From: Bill Fenner <fenner@parc.xerx.com>

To: Davidwfox@eworld.com

CC: rem-conf@es.net

Subject: Re: ISDN & M-Bone

In message <950830154851_14164706@eWorld.com> you write:

>Just about to install 128k ISDN connected to Mac server network in our home. Will we be able to connect to the M-Bone and if so, what special equipment do we need?<

I occasionally run a tunnel over my ISDN link, it works very well for audio and if you do priority dropping you can get some vague idea of what the video is supposed to look like. You need a multicast capable router at your home. I'm pretty sure that MacTCP doesn't do multicast forwarding; I don't know if MachTen does or not. You might need to find a UNIX box (e.g. a cheap PC running FreeBSD) to put at your end. Or, if the ends of the ISDN line are real routers, (as opposed to a bridge), you might be able to turn on multicast forwarding on them. Bill

---

Date: Sun, 28 Aug 1994 20:20:49 +0900

From: Hitoaki Sakamoto <hitoaki@sphere.csl.ntt.jp>

To: rem-conf@es.net, MBONE@isi.edu

Subject: Re: ISDN, PPP, and MBONE

<Does anyone know of someone using ISDN to support an MBONE connection? I would be particularly interested to know if anyone is using an SGI Indy or Sun (which have a ISDN port) with ISDN for MBONE use.>

I am using the MBONE with ISDN at home. I have a Sun IPX with ISDN S-bus board (from CSR, not SUN original). This board is very useful, because it can use 2 B ch (128 Kbps).

Date: Sat, 27 Aug 1994 22:22:31 -0700

From: Paul Traina <pst@cisco.com>

To: Michael Macedonia<macedoni@fravyl.cs.nps.navy.mil>

Cc: MBONE@ISI.EDU

Subject: Re: ISDN, PPP, and MBONE

<Does anyone know of someone using ISDN to support an MBONE connection?>

Yes, I am using PPP over ISDN, however I'm using PIM/sparse as opposed to DVMRP to carry my routing information. DVMRP (and PIM/dense) is not well suited to using a low bandwidth link with a low threshold limit (as an example, a link between work and a telecomuter at home who want's to receive local work multicast transmissions) because you get periodic blasts of multicast traffic until your prune messages get back (assuming you have a mrouted that listens to prunes at all). Before I switched to using PIM in sparse mode, every time a prune message would expire, I'd get a blast of packets down my link until the packets were processed and a prune message was sent back. Now you'd tend to think that this should happen really fast, and it does, but it's really annoying to see that 1 second freeze every n seconds.

Return-Path: <e93_mda@it.kth.se>

To: lrmihlon@nps.navy.mil (Lauren R Mihlon)

CC: magda@it.kth.se, e93_mda@it.kth.se

Subject: Re: ISDN and MBONE

Date: Tue, 09 Jul 1996 22:57:36 +0200

From: Magnus Danielson<e93_mda@it.kth.se>

Hi! I think that the tech support was wrong or at least slightly wrong. Now, this is how I be.. bring MBONE to my home Indy over ISDN:

1) I run Irix 5.3

2) I have patched it with the multicast routing patch that is freely available from SGI. The kernel patch is for mrouted 3.5 and above and you also get an mrouted 3.8 along

with it.

3) I have patched the OS with the ISDN patch.

4) I have configured it to do 2 X 64 Kbps which is supported.

5) In the other end I have an Ascend primary-rate box.

6) I have a mrouted multicast router in the other end.

7) I configure a multicast tunnel between my box and the multicast router.

5.5) My Indy has its own IP number space!!!

8) The address space is split so that a 4 address range (this is called /30 for the netmask... I will use that term from this point) is dedicated to the ISDN line. The Ascend has the lower address and the Indy has the higher (or the other way around.. doesn't really matter) like this:

x.x.x.112 lower broadcast

x.x.x.113 Indy ISDN port

x.x.x.114 Ascend ISDN port

x.x.x.115 upper broadcast

These numbers shows the real layout of my box and the base

x.x.x.112 may be changed to whatever you like.

Now, the Indy ethernet port MUST be on another subnet than the ISDN port in order to allow mrouted to route traffic. This network might be as small as a /30 or bigger... so you can let the Indy route traffic to other machines.

9) I use both sd, vic and vat with success. Wb also runs great once you have learned to

avoid the x server postscript bug. Last time I tried to use sd I did have trouble.but on the other hand was the MBONE pretty upset that day so I went for a point-to-point thing instead.

I do recommend you to run the SNMP mrouted in both ends and learn to use the tools.

my home Indy was the Indy I did my half of the SNMP mrouted port on.

Good luck Magnus

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California State University, Monterey Bay
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13102 Weather Vane Way
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Monterey County Information Systems
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Director of Computing and Computer Resources (CCR)
California State University, Monterey Bay
100 Campus Center
Seaside, California 93955-8001

48. Jim Warner 1
Network Engineer, University of California Santa Cruz
CATS/Network & Telco Services
11 Communications Bldg
Santa Cruz, California 95064

49. David Warren 1
Cabrillo College
6500 Soquel Drive
Aptos, California 95003